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(54) Apparatus for vacuum-assisted light-based treatments of the skin

(57) A method and apparatus are disclosed for enhancing the absorption of light in targeted skin structures. A vacuum chamber having a clear transmitting element transparent to intense pulsed light on its proximate end and an aperture on its distal end is placed on a skin target. After applying a vacuum to the vacuum chamber and modulating the applied vacuum, the concentration of blood and/or blood vessels is increased within a pre-

termined depth below the skin surface of the skin target. Optical energy associated with light directed in a direction substantially normal to a skin surface adjoining the skin target is absorbed within the predetermined depth. The apparatus is suitable for treating vascular lesions with a reduced treatment energy density level and pain sensation than that of the prior art and for evacuating condensed vapors produced during the cooling of skin prior to firing the light with a controlled delay.

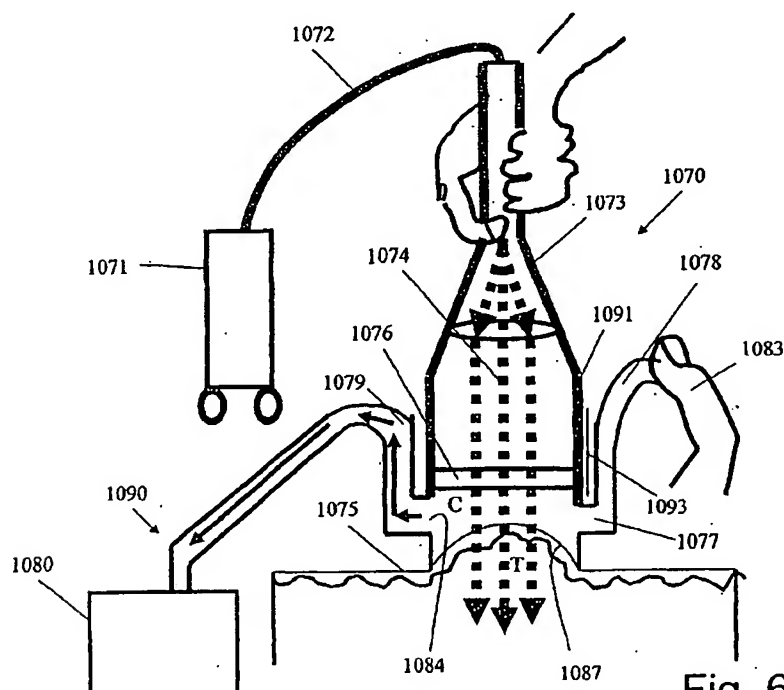


Fig. 6

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**Description**

[0001] This application claims priority from US Patent Application 11/057,542 (filed February 14, 2005), which claims priority from Israeli Patent Application No. 160510 (filed on February 22, 2004), and from US Patent Application 10/498,382 (filed June 10, 2004), which is a Continuation-In-Part of PCT/IL02/00635 (filed on August 2, 2002), which is derived from IL 147009 (filed on December 10, 2001) and from IL 150094 (filed on June 6, 2002).

**Field of the Invention**

[0002] The present invention is related to the field of light-based skin treatments. More specifically, the invention is related to the utilization of light sources for the non-invasive treatment of skin disorders under the skin surface, whereby light is selectively absorbed by hair shafts, blood vessels, or collagen bundles, for the treatment or destruction of unwanted hairs, of blood vessels, or of other skin disorders.

**Background of the Invention**

[0003] Prior art very high intensity, short duration pulsed light systems which operate in the visible part of the spectrum, such as flashlamps or intense pulsed lasers are currently used in aesthetic treatments by one of two known ways: a) Applying the light to the skin without applying any pressure on the treatment zone, so as not to interfere with the natural absorption properties of skin; and b) Applying pressure onto the skin by means of the exit window of the treatment device in contact with the skin, thereby expelling blood from the light path within the skin and enabling better transmission of the light to a skin target in cases where the spectral lines of the treatment light source match absorption lines of the blood.

[0004] The major applications of intense pulsed light or intense pulsed laser systems are hair removal, coagulation of blood vessels for e.g. port wine stains, telangiectasia, spider veins and leg veins, multiple heating of blood vessels for e.g. rosacea, treatment of pigmented skin such as erasure of black stains and sun stains or tattoo removal, and removal of fine wrinkles by heating the tissue around the wrinkles, normally referred to as photorejuvenation.

[0005] US Patent Nos. 5,226,907, 5,059,192, 5,879,346, 5,066,293, 4,976,709, 6,120,497, 6,120,497, 5,626,631, 5,344,418, 5,885,773, 5,964,749, 6,214,034 and 6,273,884 describe various laser and non-coherent intense pulsed light systems. These prior art light systems are not intended to increase the natural absorption of the skin.

[0006] Applying a vacuum to the skin is a known prior art procedure, e.g. for the treatment of cellulites, which complements massaging the skin. Such a procedure produces a flow of lymphatic fluids so that toxic substances may be released from the tissue. As the vacuum is applied, a skin fold is formed. The skin fold is raised above the surrounding skin surface, and the movement of a handheld suction device across the raised skin performs the massage. The suction device is moved in a specific direction relative to the lymphatic vessels, to allow lymphatic fluids to flow in their natural flow direction. The lymphatic valve in each lymphatic vessel prevents the flow of lymphatic fluid in the opposite direction, if the suction device were moved incorrectly. Liquids generally accumulate if movement is not imparted to the raised skin. The massage, which is generally carried out by means of motorized or hand driven wheels or balls, draws lymphatic fluids from cellulite in the adipose subcutaneous region and other deep skin areas, the depth being approximately 5-10 mm below the dermis.

[0007] US Patent No. 5,961,475 discloses a massaging device with which negative pressure is applied to the skin together during massaging. A similar massaging device which incorporates a radio frequency (RF) source for the improvement of lymphatic flow by slightly heating the adipose tissue is described in US Patent No. 6,662,054. Some massaging systems, such as those produced by Deka and Cynosure, add a low power, continuous working (CW) light source of approximately 0.1-2 W/cm<sup>2</sup>, in order to provide deep heating of the adipose tissue by approximately 1-3°C degrees and to enhance lymphatic circulation. The light sources associated with vacuum lymphatic massage devices are incapable of inducing blood vessel coagulation due to their low power. Also, prior art vacuum lymphatic massage devices are adapted to induce skin protrusion or to produce a skin fold by applying a vacuum.

[0008] Selective treatment of blood vessels by absorption of intense pulsed laser radiation is possible with Dye lasers operating at 585 nm, as well as with other types of lasers. Photorejuvenation has also been performed with Diode lasers in the near infrared spectral band of 800-980 nm and with Nd:YAG lasers having a frequency of approximately 1064 nm with limited success. The light emitted by such lasers is not well absorbed by tiny blood vessels or by the adjoining liquid. Broad band non-coherent intense pulsed light systems are also utilized for photorejuvenation with some success, although requiring more than 10 repeated treatments. The heat which is absorbed by the blood vessels, as a result of the light emitted by the intense short pulse devices, is transferred to adjacent collagen bundles.

[0009] The absorption of pulsed Diode and Nd:YAG laser beams by blood vessels is lower than the absorption of pulsed Dye laser beam. In order to compensate for limited photorejuvenation with red and infrared intense pulsed light and laser systems, a very high energy density as high as 30-60 J/cm<sup>2</sup> needs to be generated. At such an energy density, the melanin-rich epidermis, particularly in dark skin, is damaged if not chilled. A method to reduce the energy density of

intense pulsed lasers or non-coherent intense pulsed light sources which operate in the visible or the near infrared regions of the spectrum will therefore be beneficial.

[0010] Pulsed dye lasers operating in the yellow spectral band of approximately 585-600 nm, which is much better absorbed by blood vessels, are also utilized for the smoothing of fine wrinkles. The energy density of light emitted by Dye lasers, which is approximately 3-5 J/cm<sup>2</sup>, is much lower than that of light emitted by other lasers. However, the pulse durations of light emitted by Dye lasers are very short, close to 1 microsecond, and therefore risk the epidermis in darker skin. Treatments of wrinkles with Dye lasers are slow, due to the low concentration of absorbing blood vessels, as manifested by the yellow or white color of treated skin, rather than red or pink characteristic of skin having a high concentration of blood vessels. Due to the low energy density of light emitted by Dye lasers, as many as 10 treatments may be necessary. A method to reduce the energy density of light generated by Dye lasers, or to reduce the number of required treatments at currently used energy density levels, for the treatment of fine wrinkles, would be beneficial.

[0011] Pulsed Dye lasers operating at 585 nm are also utilized for the treatment of vascular lesions such as port wine stains or telangiectasia or for the treatment of spider veins. The energy density of the emitted light is approximately 10-15 J/cm<sup>2</sup>, and is liable to cause a burn while creating the necessary purpura. A method to reduce the energy density of light emitted by Dye lasers for the treatment of vascular lesions would be highly beneficial.

[0012] Hair removal has been achieved by inducing the absorption of infrared light, which is not well absorbed by melanin present in hair strands, impinging on blood vessels. More specifically, absorption of infrared light by blood vessels at the distal end of hair follicles contributes to the process of hair removal. High intensity pulsed Nd:YAG lasers, such as those produced by Altus, Deka, and Iridex, which emit light having an energy density of more than 50 J/cm<sup>2</sup>, are used for hair removal. The light penetration is deep, and is often greater than 6 millimeters. Some intense pulsed light or pulsed laser systems, such as that produced by Syneron, used for hair removal or photorejuvenation also employ an RF source for further absorption of energy within the skin.

[0013] The evacuation of smoke or vapor, which is produced following the impingement of monochromatic light on a skin target, from the gap between the distal end window of a laser system and the skin target, is carried out in conjunction with prior art ablative laser systems such as CO<sub>2</sub>, Erbium or Excimer laser systems. The produced smoke or vapor is usually purged by the introduction of external fresh air at greater than atmospheric pressure.

[0014] Coagulative lasers such as pulsed dye lasers or pulsed Nd:YAG lasers, which treat vascular lesions under the skin surface without ablating the skin surface, are generally not provided with an evacuation chamber which produces subatmospheric pressure over a skin target.

[0015] Some prior art intense pulsed laser systems, which operate in the visible and near infrared region of the spectrum and treat lesions under the skin surface, e.g. vascular lesions, with pulsed dye laser systems or pulsed Nd:YAG lasers, employ a skin chilling system. Humidity generally condenses on the distal window, due to the use of a skin chilling system. The humidity is not caused by the skin treatment, but rather by the low temperature of the distal window. It would be advantageous to evacuate the condensed vapors from the distal window of the laser system prior to the next firing of the laser.

[0016] US Patent Nos. 5,595,568 and 5,735,844 describe a coherent laser system for hair removal whereby pressure is applied to the skin by a transparent contact device in contact therewith, in order to expel blood present in blood vessels from a treatment zone. In this approach blood absorption decreases in order to increase subcutaneous light penetration.

[0017] US Patent Nos. 5,630,811 and 5,853,407 also describe a coherent laser system for hair removal which restricts local blood flow, in order to reduce damage to the skin tissue surrounding the hairs. Local tissue structures are flattened by applying positive pressure or negative pressure to the skin. The treatment beam is limited to only 5 mm. The treatment beam is not suitable for a larger treatment spot per pulse of approximately 40 mm. Blood expulsion is not uniform and not instantaneous for such large treatment spots, and therefore blood may remain in the skin tissue after the laser beam has been fired. Also, a large-diameter treatment device may not be easily repositioned to another treatment site, due to the relatively high lifting force needed when negative pressure is applied to the skin. Furthermore, this laser system does not provide any means for preventing gel obstruction when negative pressure is applied to the skin. Although applying a flattening positive pressure or negative pressure to a small-diameter treatment area enhances hair removal, the treatment of vascular lesions is not improved since fewer blood vessels are present within the treatment area due to the blood expulsion. A need therefore exists for a vacuum-assisted device that can alternatively reduce or increase the blood volume fraction within a skin target.

[0018] The light-based non-ablative treatment of hair or of vascular lesions is often very painful, particularly during the treatment of dark and thick unwanted hairs which may appear in a bikini line, on the legs, or on the back. A pain sensation is felt with almost all types of light based devices for hair removal, including intense pulsed light sources and lasers.

[0019] The aforementioned prior art efforts to expel blood vessels help in some cases to avoid unnecessary damage to skin structures which are not intended to be treated, such as unnecessary coagulation of blood vessels during a hair removal treatment, while increasing hair removal efficacy. The reduction in damage to skin structures does not alleviate the immediate pain sensed during a treatment, but rather, the expulsion of blood causes a higher exposure of the hair

shaft to a treatment pulse of light, resulting in a higher hair follicle temperature and a correspondingly higher level of acute pain due to excessive heating of the nerves which surround the hair shafts. Furthermore, the expelling of blood from one skin area increases the fractional blood volume in adjacent areas, causing a risk of thermal damage if the treatment light diffuses to the adjacent blood rich zone. It is well known to light-based hair removal practitioners that acute pain is felt during the treatment when hairy areas, particularly characterized by dark thick hair, are impinged by the treatment beam, whereas firing the light beam on a hairless area is substantially painless. It can therefore be concluded that the pain which is sensed during a hair removal treatment is generated by nerves surrounding the hair shafts, and not by nerves distributed in other areas of the skin. There is therefore a need for an improved apparatus for pain reduction without having to reduce the treatment energy density.

**[0020]** Two types of a pain sensation caused by light-based aesthetic treatments are recognizable: immediate sharp pain and long term milder pain. The immediate sharp pain is felt during each treatment pulse and increases to an intolerable sensation after a few shots, necessitating a patient to rest during a long delay before continuing the treatment. The treatment rate, particularly for large areas such as on the legs, is therefore considerably reduced. Depending on his pain tolerance, the patient may even decide not to continue the treatment. The sharp pain is caused by the exposure of treatment light to nerve endings located in the epidermis and dermis, by sensory receptors of hair shafts located deep in the dermis, or by the stimulation of nerves surrounding the hair bulbs as the hair shafts are being heated during the treatment, often at a temperature of approximately 70°C.

**[0021]** The less acute, long term milder pain is caused by the accumulative increase of skin temperature following treatment, e.g. during a period ranging from 10 minutes to a day after treatment, which is approximately 3 to 5 °C above body temperature. The increase in skin temperature may induce redness and edema, causing pain, depending on the hair density and the fractional blood volume within the adjoining tissue. The application of a cold gauze immediately after the treatment usually helps to avoid the post-treatment pain.

**[0022]** The most common prior art method for alleviating or preventing the immediate sharp pain caused by the non-ablative treatment of hair or of vascular lesions with intense pulsed light is the application of EMLA cream produced by AstraZeneca Canada Inc. Such cream is a topical anesthetic applied to the skin approximately 30-60 minutes before a treatment, which numbs the skin and decreases the sensation of pain. This prior art method is generally impractical due to the long and inconvenient waiting time between the application of the EMLA cream and the treatment. Since health professionals prefer to maximize the number of patients to be treated during a given time period, the health clinic must provide a large waiting room for those patients that are waiting to be treated by intense pulsed light following the application of the EMLA cream.

**[0023]** Pain caused by the non-ablative treatment of hair or of vascular lesions may also be alleviated or prevented by reducing the energy density of the intense pulsed light. Energy density reduction, however, compromises the treatment quality, and therefore is an unacceptable solution, particularly due to the relatively high cost of treatment.

**[0024]** US Patent Nos. 6,264,649 and 6,530,920 disclose a cooling head for a skin treatment laser and a method to reduce or eliminate pain during laser ablative treatments of the skin by cooling the skin surrounding the treatment area. The pain is associated with the ablation or burning of a skin surface during skin resurfacing. An extraction port of the cooling head enables removal of debris material, such as smoke produced by the skin treatment laser, from the treatment area and for connection to a vacuum source. Evacuated vapor such as smoke is replaced by fresh and clean air.

**[0025]** With respect to prior art smoke evacuation devices, a significant subatmospheric pressure is generally not generated over a skin surface due to the introduction of fresh atmospheric pressure air. If subatmospheric pressure were maintained over a skin surface, the treatment handpiece would be prevented from being lifted and displaced from one skin site to another during the treatment process. Additionally, prior art smoke evacuation devices are not associated with non-ablative lasers, such as a long-pulse Nd:YAG laser, which treat tissue only under the skin surface and do not produce smoke resulting from the vaporization of the skin surface. Furthermore, the application of heat releasing gel onto a skin target is not conducive for the ablation of a skin surface or for the subsequent evacuation of debris material since the gel forms a barrier between the skin surface and the surrounding air.

**[0026]** Current laser and IPL skin treatment systems utilize chilling means. However, pain is still noticeable.

**[0027]** A need therefore exists for alleviating the resulting pain caused by the treatment of unwanted hair, unwanted wrinkles or vascular lesions by intense pulsed light or intense pulsed laser systems, without reducing the light source intensity, without applying a topical anesthetic, and without using a chiller as means to reduce pain.

**[0028]** It is an object of the present invention to provide a method and apparatus for the treatment of subcutaneous lesions, such as vascular lesions, by a non-ablative, high intensity pulsed laser or light system operating at wavelengths shorter than 1800 nm which does not damage the surface of the skin or the epidermis.

**[0029]** It is an object of the present invention to provide a method and apparatus for controlling the depth of subcutaneous light absorption.

**[0030]** It is an object of the present invention to provide a method and apparatus for increasing the absorption of light which impinges a skin target by increasing the concentration of blood vessels thereat.

**[0031]** It is an additional object of the present invention to provide a method and apparatus by which the energy density



level of intense pulsed light that is suitable for hair removal, fine wrinkle removal, including removal of wrinkles around the eyes and in the vicinity of the hands or the neck, and the treatment of port wine stain or rosacea may be reduced relative to that of the prior art.

**[0032]** It is an additional object of the present invention to provide a method and apparatus by which the number of required treatments for hair removal, fine wrinkle removal, including removal of wrinkles around the eyes and in the vicinity of the hands or the neck, and the treatment of port wine stain or rosacea at currently used energy density levels may be reduced relative to that of the prior art.

**[0033]** It is yet an additional object of the present invention to provide a method and apparatus for repeated evacuation, prior to the firing of a subsequent light pulse, of vapors which condense on the distal window due to the chilling of laser treated skin.

**[0034]** It is yet an additional object of the present invention to provide a method and apparatus for alleviating the resulting pain caused by the treatment of unwanted hair, unwanted wrinkles or vascular lesions by intense pulsed light or intense pulsed laser systems, without reducing the light source intensity, without applying a topical anesthetic, and without relying on skin chilling for pain reduction.

**[0035]** It is yet an additional object of the present invention to provide a method and apparatus for speedy repositioning of a vacuum-assisted, non-ablative light-based treatment handpiece from one site to another.

**[0036]** It is yet an additional object of the present invention to provide a method and apparatus for a vacuum-assisted, light-based skin treatment which is conducive for the application of a heat releasing gel onto a skin surface, without resulting in obstruction of vacuum generating apparatus.

**[0037]** It is a further object of the present invention to provide an apparatus for vacuum-assisted, light-based treatment which can be held by one hand while a light treatment handpiece is held by the other hand.

**[0038]** Other objects and advantages of the invention will become apparent as the description proceeds.

#### Summary of the Invention

**[0039]** The present invention is directed to apparatus for vacuum-assisted light-based skin treatments. The apparatus comprises a vacuum chamber which is transparent or translucent to intense pulsed monochromatic or non-coherent light directed to a skin target. A vacuum is applied to said vacuum chamber, whereby said skin target is drawn to said vacuum chamber. The efficacy and utility of the apparatus are achieved by employing the apparatus in two modes: (a) in a vacuum applying mode wherein a high vacuum level ranging from 0-1 atmospheres is attained and (b) in a vacuum release mode upon deactivation of the light source and of the vacuum pump after optical energy associated with the directed light has been absorbed within a predetermined depth under the skin surface, wherein atmospheric air is introduced to the vacuum chamber so that the vacuum chamber may be speedily repositioned to another skin target.

**[0040]** In one embodiment of the invention, the apparatus comprises:

- a) a non-ablative intense pulsed monochromatic or non-coherent light source;
- b) a vacuum chamber placeable on a skin target which has an opening on the distal end thereof and provided with a clear transmitting element on the proximate end thereof, said transmitting element being transparent or translucent to light generated by said source and directed to said skin target;
- c) means for applying a vacuum to said vacuum chamber, the level of the applied vacuum suitable for drawing said skin target to said vacuum chamber via said opening; and
- d) means for preventing influx of air into vacuum chamber during a vacuum applying mode.

**[0041]** As referred to herein, "distal" is defined as a direction towards the exit of the light source and "proximate" is defined as a direction opposite from a distal direction.

**[0042]** The terms "evacuation chamber" and "vacuum chamber" as referred to herein are interchangeable.

**[0043]** The vacuum chamber is advantageously one-hand graspable by means of a handle connected thereto so that the vacuum chamber can be held by one hand while a light treatment handpiece is held by the other hand.

**[0044]** Preferably-

- a) the vacuum applying means comprises a vacuum pump and at least one control valve;
- b) the wavelength of the light ranges from 400 to 1800 nm;
- c) the pulse duration of the light ranges from 10 nanoseconds to 900 msec;
- d) the energy density of the light ranges from approximately 2 to approximately 150 J/ cm<sup>2</sup>;
- e) the level of applied vacuum within the vacuum chamber ranges from approximately 0 to approximately 1 atmosphere;
- f) the light source is selected from the group of Dye laser, Nd:YAG laser, Diode laser, light emitting diode, Alexandrite laser, Ruby laser, Nd:YAG frequency doubled laser, Nd:Glass laser, a non-coherent intense pulse light source, and

a non-coherent intense pulse light source combined with an RF source;

g) the light is suitable for hair removal, collagen contraction, photorejuvenation, treatment of vascular lesions, treatment of sebaceous or sweat glands, treatment of warts, treatment of pigmented lesions, treatment of damaged collagen, treatment of acne, treatment of warts, treatment of keloids, treatment of sweat glands, and treatment of psoriasis;

h) the light is suitable for the treatment of vascular lesions selected from the group of port wine stains, telangiectasia, rosacea, and spider veins;

i) the clear transmitting element is suitable for transmitting the light in a direction substantially normal to a skin surface adjoining said skin target;

j) the clear transmitting element is separated from the adjoining skin surface by a gap ranging from 0.5 to 50 mm, and preferably approximately 2 mm;

k) the treatment spot per pulse is greater than 5 mm, and preferably between 15 to 50 mm;

l) the influx of air into vacuum chamber during a vacuum applying mode is prevented by means of a control valve and control circuitry or by means of manual occlusion of a vacuum chamber conduit;

m) the ratio of the maximum length to maximum width of the aperture formed on the distal end of the vacuum chamber ranges from approximately 1 to 4;

n) the vacuum chamber has at least one suction opening, the vacuum being applied to the vacuum chamber via said at least one suction opening;

o) the vacuum chamber is U-shaped; and

p) the vacuum chamber is provided with a rim for sealing the peripheral contact area between the skin surface adjoining the skin target and the vacuum chamber wall.

**[0045]** Preferably, the apparatus further comprises control means for controlling operation of the vacuum pump, the at least one control valve, and the light source. The control means is selected from the group of electronic means, pneumatic means, electrical means, and optical means. The control means may be actuated by means of a finger depressable button, which is positioned on a light treatment handpiece.

**[0046]** In one aspect, the control means is suitable for firing the light source after a first predetermined delay, e.g. from approximately 0.5 sec to approximately 4 seconds, following operation of the vacuum pump.

**[0047]** In one aspect, the control means is suitable for firing the light source after a predetermined delay following opening of the at least one control valve.

**[0048]** In one aspect, the control means is suitable for increasing the pressure in the vacuum chamber to atmospheric pressure following deactivation of the light source, to allow for effortless repositioning of the vacuum chamber to a second skin target. The increase in vacuum chamber pressure may be triggered by means of a light detector which transmits a signal to the control means upon sensing a significant decrease in optical energy generated by the light source or may be effected after a second predetermined delay, following deactivation of the light source.

**[0049]** In one aspect, the control means is suitable for verifying that a desired energy density level of the light is being directed to the skin target and for deactivating the light source if the energy density level is significantly larger than said desired level.

**[0050]** In one aspect, the vacuum chamber is connected to, or integrally formed with, a proximately disposed handpiece through which light propagates towards the skin target. The vacuum chamber has a proximate cover formed with an aperture, said cover being attachable or releasably attachable to a handpiece such as a light guide having an integral clear transmitting element.

**[0051]** In one aspect, the vacuum pump is an air pump.

**[0052]** In one aspect, the vacuum pump is a peristaltic pump for drawing air and gel from the interior of the vacuum chamber via a hose connected to a conduit in communication with the interior of the vacuum chamber.

**[0053]** The hose provides indication means that the skin target has undergone a light-based treatment by means of gel which is discharged from an end of the hose onto a skin surface during a vacuum applying mode.

**[0054]** In one aspect, the apparatus further comprises means to stabilize the vacuum chamber on a substantially non-planar skin surface.

**[0055]** In one aspect, the apparatus further comprises a skin contact detector for sensing the placement of the vacuum chamber onto the skin target and for generating a first signal to activate the vacuum pump following placement of the vacuum chamber onto the skin target.

**[0056]** In one aspect, the control valve is opened following generation of a second signal by means of a light detector which is adapted to sense termination of the light directed to the skin target, atmospheric pressure air thereby being introduced to the interior of the vacuum chamber.

**[0057]** In one aspect, the second signal is suitable for deactivating the vacuum pump.

**[0058]** In another embodiment of the invention, the apparatus further comprises an array of vacuum chambers placeable on a skin surface. The array is formed from a single sheet made of material which is transparent or translucent to

the light, said sheet being formed with a plurality of conduits for air evacuation such that each of said conduits is in communication with a corresponding vacuum chamber. The distance between adjacent vacuum chambers is sufficiently small to allow light which has diffused from the interior of each chamber to treat a skin area located underneath a corresponding conduit.

5 [0059] Each conduit preferably branches into first and second portions which are in communication with a vacuum pump and with a source of compressed air, respectively.

[0060] In one aspect, each vacuum chamber is provided with a contact detector for triggering a signal to activate the vacuum pump, two control valves to control the passage of fluid through the corresponding first and second conduits portions, respectively, and a light detector which generates a signal to introduce compressed air through the correspond-

10 [0061] In one aspect, the first conduit portions are arranged such that the air from all vacuum chambers is evacuated simultaneously upon activation of the vacuum pump.

[0062] In another embodiment of the invention, the vacuum applying means comprises a vertically displaceable cover to which the clear transmitting element is secured and chamber walls which surround, and are of a similar shape as, said cover, a vacuum being generated within a vacuum chamber defined by the volume between said cover, said walls, and the skin target upon proximal displacement of said cover relative to said walls. The means for preventing influx into the vacuum chamber is a sealing element which is secured to the outer periphery of the cover and resiliently contacts the chamber walls.

20 [0063] In one aspect, a proximally directed force or distally directed force is generated by any means selected from the group of a plurality of solenoids, a spring assembly, and a pneumatic device, or a combination thereof, which are deployed around the periphery of the cover and connected to the walls, and is controllable so as to adjust the height of the drawn skin target relative to the adjoining skin surface. Due to their low power consumption, a 1.5 V battery may be used to energize the solenoids.

[0064] The apparatus preferably further comprises an aeration tube for introducing atmospheric air to the vacuum chamber during a vacuum release mode. The aeration tube is in communication with a valve which is actuated upon conclusion of a skin target treatment.

25 [0065] In one aspect, the proximally directed force is supplemented by means of a vacuum pump.

[0066] In another embodiment of the invention, the apparatus comprises means for preventing passage of skin cooling gel to the vacuum applying means.

30 [0067] In one aspect, the means for preventing passage of gel to the vacuum applying means comprises a trap, a first conduit through which gel and air are drawn from the vacuum chamber to said trap, a second conduit through which air is drawn from said trap to the vacuum pump, and optionally, a filter at the inlet of the first and second conduits.

[0068] In one aspect, the trap is suitable for the introduction therein of an ion exchange resin with which the gel is boundable.

35 [0069] In one aspect, the means for preventing passage of gel is a detachable vacuum chamber upper portion, detachment of said upper portion allowing removal of gel retained within the vacuum chamber interior. Suitable apparatus comprises an upper portion having an open central area, a clear transmitting element attached to said upper portion, vacuum chamber walls, a vacuum chamber cover perpendicular to said walls and suitably sized so as to support said upper portion, and a plurality of attachment clips pivotally connected to a corresponding vacuum chamber wall for detachably securing said upper portion to said vacuum chamber cover.

40 [0070] In one aspect, the vacuum chamber walls are coated with a hydrophobic material. Accordingly, the vacuum chamber provides indication that the skin target has undergone a light-based treatment by means of gel which falls to the skin surface during a vacuum release mode in the shape of the distal end of the vacuum chamber walls.

45 [0071] In one aspect, the at least one suction opening is sufficiently spaced above the distal end of a vacuum chamber wall and from the centerline of the vacuum chamber so as to prevent obstruction of the at least one suction opening by gel and drawn skin upon application of the vacuum.

[0072] In another embodiment of the invention, the apparatus further comprises means for skin cooling, said skin cooling means adapted to reduce the rate of temperature increase of the epidermis at the skin target. The level of the applied vacuum is suitable for evacuating condensed vapors which are produced within the gap between the clear transmitting element and the skin target and condense on the clear transmitting element during the cooling of skin.

50 [0073] In one aspect, the skin cooling means is a metallic plate in abutment with the vacuum chamber on the external side thereof, said plate being cooled by means of a thermoelectric cooler. The plate may be positionable on the skin surface adjoining said skin target in order to cool the lateral sides of the vacuum chamber or may be in contact with the clear transmitting element.

55 [0074] In one aspect, the skin cooling means is a polycarbonate layer transparent to the directed light which is attached to the distal face of the clear transmitting element.

[0075] In one aspect, the skin cooling means is a gel, a low temperature liquid or gas applied onto the skin target.

[0076] In another embodiment of the invention, the apparatus is suitable for controlling the depth of light absorption

by blood vessels under a skin surface, comprising:

- a) a vacuum chamber placed on a skin target which is formed with an aperture on the distal end thereof and provided with a clear transmitting element on the proximate end thereof, said transmitting element being transparent or translucent to intense pulsed monochromatic or non-coherent light directed to said skin target and suitable for transmitting the light in a direction substantially normal to a skin surface adjoining said skin target;
- b) means for applying a vacuum to said vacuum chamber, the level of the applied vacuum suitable for drawing said skin target to said vacuum chamber via said aperture; and
- c) means for inducing an increase in the concentration of blood and/or blood vessels within a predetermined depth below the skin surface of said skin target, optical energy associated with the directed light being absorbed within said predetermined depth.

[0077] As referred to herein, the term "blood volume fraction" is interchangeable with "the concentration of blood and/or blood vessels within a predetermined depth below the skin surface".

[0078] In one embodiment, the means for inducing an increase in the concentration of blood and/or blood vessels within a predetermined depth below the skin surface of said skin target is a means for modulating the applied vacuum.

[0079] The depth under the skin surface at which optical energy is absorbed may be selected in order to thermally injure or treat predetermined skin structures located at said depth. As referred to herein, a "skin structure" is defined as any any damaged or healthy functional volume of material located under the epidermis, such as blood vessels, collagen bundles, hair shafts, hair follicles, sebaceous glands, sweat glands, adipose tissue. Depending on the blood concentration within the skin target, the light may propagate through the skin surface and upper skin layers without being absorbed thereat and then being absorbed at a skin layer corresponding to that of a predetermined skin structure. As referred to herein, the term "light" means both monochromatic and non-coherent light. The terms "light absorption" and "optical energy absorption" refer to the same physical process and are therefore interchangeable.

[0080] In contrast with a prior art vacuum-assisted apparatus for laser or intense pulsed light treatment wherein a sharp skin fold is produced through a slit following application of the vacuum, vacuum-assisted drawn skin by means of the apparatus of the present invention is not distorted, but rather is slightly and substantially uniformly drawn to the vacuum chamber, protruding approximately 1-2 mm from the adjoining skin surface. The maximum protrusion of the drawn skin from the adjoining skin surface is limited by a clear transmitting element defining the proximate end of the vacuum chamber. The clear transmitting element is separated from the adjoining skin surface by a gap of preferably 2 mm, and ranging from 0.5-50 mm. In one embodiment of the invention, the drawn skin abuts the clear transmitting element.

[0081] As referred to herein, "vacuum modulation" means adjustment of the vacuum level within, or of the frequency by which vacuum is applied to, the vacuum chamber. By properly modulating the vacuum, the blood flow rate, in a direction towards the vacuum chamber, within blood vessels at a predetermined depth below the skin surface can be controlled. As the concentration of blood and/or blood vessels is increased within the skin target, the number of light absorbing chromophores is correspondingly increased at the predetermined depth. The value of optical energy absorbance at the predetermined depth, which directly influences the efficacy of the treatment for skin disorders, is therefore increased.

[0082] Preferably-

- a) The wavelength of the light ranges from 400 to 1800 nm.
- b) The pulse duration of the light ranges from 10 nanoseconds to 900 msec.
- c) The energy density of the light ranges from 2 to 150 J/ cm<sup>2</sup>.
- d) The ratio of the maximum length to maximum width of the aperture formed on the distal end of the vacuum chamber ranges from approximately 1 to 4.
- e) The level of the applied vacuum within the vacuum chamber ranges from 0 to 1 atmosphere.
- f) The frequency of vacuum modulation ranges from 0.2 to 100 Hz.
- g) The light is fired after a predetermined delay following application of the vacuum.
- h) The predetermined delay ranges from approximately 10 msec to approximately 1 second.
- i) The duration of vacuum application to the vacuum chamber is less than 2 seconds.
- j) Vacuum modulation is electronically controlled.

[0083] In one embodiment of the invention, the means for inducing an increase in the concentration of blood and/or blood vessels within a predetermined depth below the skin surface of said skin target is at least one support element positioned at a skin area adjoining the skin target and having a thickness suitable for inducing an increase in the concentration of blood and/or blood vessels within said predetermined depth. The apparatus may further comprise at least one leg having a thickness considerably less than the at least one support element and positioned at the periphery of the vacuum chamber, said at least one leg being separated from an adjacent support element, the at least one support

element being adapted to urge blood expelled by said at least one leg towards the skin target.

**[0084]** The predetermined depth under the skin surface at which optical energy is absorbed is selected in order to thermally injure or treat predetermined skin structures located at said depth.

**[0085]** Due to implementation of the apparatus, the treatment energy density level for various types of treatment is significantly reduced, on the average of 50% with respect with that associated with prior art devices. The treatment energy density level is defined herein as the minimum energy density level which creates a desired change in the skin structure, such as coagulation of a blood vessel, denaturation of a collagen bundle, destruction of cells in a gland, destruction of cells in a hair follicle, destruction of unwanted lesions by means of photodynamic therapy, or any other desired effects. The following is the treatment energy density level for various types of treatment performed with use of the present invention:

a) treatment of vascular lesions, port wine stains, telangiectasia, rosacea, and spider veins with light emitted from a dye laser unit and having a wavelength of 585 nm: 5-12 J/cm<sup>2</sup>;

b) treatment of vascular lesions, port wine stains, telangiectasia, rosacea, and spider veins with light emitted from a diode laser unit and having a wavelength of 940 nm: 10-30 J/cm<sup>2</sup>;

c) treatment of vascular lesions with light emitted from an intense pulsed non-coherent light unit and having a wavelength of 570-900 nm: 5-20 J/cm<sup>2</sup>;

d) photorejuvenation with light emitted from a dye laser unit and having a wavelength of 585 nm: 1-4 J/cm<sup>2</sup>;

e) photorejuvenation with light emitted from an intense pulsed non-coherent light unit and having a wavelength of 570-900 nm: 5-20 J/cm<sup>2</sup>;

f) photorejuvenation with a combined effect of light emitted from an intense pulsed non-coherent light unit and having a wavelength of 570-900 nm and of a RF source: 10 J/cm<sup>2</sup> for both the intense pulsed non-coherent light unit and RF source;

g) hair removal with light emitted from a Nd:YAG laser unit and having a wavelength of 1604 nm: 25-35 J/cm<sup>2</sup>; and

h) Porphyrin-based photodynamic therapy with light emitting diodes delivering blue light (420 nm), orange light (585 nm), or red light (630 nm): 5-20 J/cm<sup>2</sup>.

**[0086]** The preferably further comprises a control unit for controlling operation of the vacuum applying means and light source. The control unit is also suitable for controlling operation of at least one control valve in communication with the vacuum chamber, for firing the light after a predetermined delay following application of the vacuum, and for electronically modulating the vacuum.

**[0087]** In one aspect, the apparatus further comprises a skin contact detector for sensing the placement of the vacuum chamber onto the skin target, the control unit being suitable for activating the vacuum applying means in response to a signal transmitted by said skin contact detector.

**[0088]** In one aspect, the apparatus further comprises a light detector for sensing the termination of the light directed to the skin target, the control unit being suitable for regulating a control valve in response to a signal transmitted by said light detector so as to introduce atmospheric pressure air to the interior of the vacuum chamber.

**[0089]** In one aspect, the apparatus further comprises a pulsed radio frequency (RF) source for directing suitable electromagnetic waves to the skin target. The frequency of the electromagnetic waves ranges from 0.2-10 MHz. The RF source is either a bipolar RF generator which generates alternating voltage applied to the skin surface via wires and electrodes or a monopolar RF generator with a separate ground electrode. The control unit is suitable for transmitting a first command pulse to the at least one control valve and a second command pulse to both the intense pulsed light source and RF source.

**[0090]** In one aspect, the apparatus further comprises an erythema sensor, said sensor suitable for measuring the degree of skin redness induced by the vacuum applying means. The control unit is suitable for controlling, prior to firing the light source, the energy density of the light emitted from the light source, in response to the output of the erythema sensor.

**[0091]** In one aspect, the vacuum chamber has a proximate cover formed with an aperture, said cover being attachable to a handpiece, such as a light guide, having an integral clear transmitting element.

**[0092]** In one aspect, the apparatus further comprises means for skin cooling, said skin cooling means adapted to reduce the rate of temperature increase of the epidermis at the skin target.

**[0093]** In one aspect, the apparatus further comprises means for preventing passage of skin cooling gel to the vacuum applying means.

**[0094]** In another embodiment of the invention, the apparatus is suitable for alleviating or preventing pain caused by a non-ablative light-based treatment of a targeted skin structure. Accordingly, the gap separating said the clear transmitting element from the skin surface adjoining said the skin target and the magnitude of the proximally directed force resulting from said the applied vacuum in combination are suitable for drawing said the skin target to said the vacuum chamber via the opening on the distal end of the vacuum chamber said aperture until said the skin target contacts said

the clear transmitting element; and the control means is suitable for firing the light source after the first predetermined delay, following operation of the vacuum applying means.

[0095] In one aspect, the apparatus is suitable for causing the skin target to contact the clear transmitting element for a duration equal to the first predetermined delay, whereby pain signals generated by the nervous system during the treatment of the skin structure are alleviated or prevented.

[0096] The control means is preferably suitable for controlling the vacuum level generated by the vacuum applying means, and has a plurality of finger depressable buttons, each of which being adapted to set the vacuum applying means and light source at a unique combination of operating conditions so as to generate a predetermined vacuum level within the vacuum chamber and to fire the light source after a predetermined time delay following the operation of the vacuum applying means.

[0097] In one aspect, a single light source and vacuum pump are operable in conjunction with differently configured vacuum chambers, for example a vacuum chamber that is suitable for pain alleviation or a vacuum chamber that is suitable for inducing an increase in blood concentration within a skin target. Each differently configured vacuum chamber is releasably attachable to a treatment light handpiece, e.g. by means of suitable threading or clips.

### Brief Description of the Drawings

[0098] In the drawings:

- Fig. 1 is a schematic drawing which illustrates the propagation of an intense pulsed laser beam from a handpiece to a skin target according to a prior art method;
- Fig. 2 is a schematic drawing which illustrates the propagation of an intense pulsed non-coherent light beam from a handpiece to a skin target according to a prior art method;
- Fig. 3 is a schematic drawing of a prior art treatment method by which pressure is applied to a skin target, in order to expel blood from those portions of blood vessels which are in the optical path of subcutaneously scattered light;
- Fig. 4 is a schematic drawing of a prior art vacuum-assisted rolling cellulite massage device;
- Fig. 5 is a schematic drawing of a prior art vacuum-assisted hair removal device adapted to reduce the blood concentration within a skin fold formed thereby, in order to illuminate two opposed sides of the skin fold and consequently remove melanin-rich hair shafts;
- Fig. 6 is a schematic drawing of apparatus in accordance with one embodiment of the present invention, employing a manually occluded U-shaped evacuation chamber;
- Fig. 7 is a schematic drawing of apparatus in accordance with another embodiment of the present invention, employing an electronically controlled evacuation chamber;
- Fig. 8 is a schematic drawing of apparatus in accordance with the present invention, employing an intense pulsed non-coherent light source;
- Fig. 9 is a schematic drawing of apparatus in accordance with the present invention, which is provided with a skin chiller;
- Fig. 10 is a drawing which schematically illustrates the effect of applying a subatmospheric pressure to a vacuum chamber in order to increase the blood concentration in skin drawn towards the vacuum chamber;
- Fig. 11 is a drawing which schematically illustrates the increased concentration of a plurality of blood vessels in a skin target following application of a vacuum to a vacuum chamber, resulting in increased redness of skin and enhanced absorption of light;
- Fig. 12 is a photograph illustrating the change in skin color following treatment of a fine wrinkle by use of a vacuum assisted handpiece in accordance with the present invention;
- Fig. 13 is a schematic drawing of another embodiment of the invention, illustrating propagation of intense pulsed light from an external light source to a transparent modulated vacuum chamber;
- Fig. 14 schematically illustrates another embodiment of the invention which employs both an intense pulsed light source and a radio frequency source, for improved coagulation of blood vessels;
- Figs. 15a and 15b schematically illustrate a vacuum chamber which is attachable to a light guide, wherein Fig. 15a illustrates the vacuum chamber prior to attachment and Fig. 15b illustrates the vacuum chamber following attachment;
- Fig. 16 is a schematic drawing of apparatus in accordance with another embodiment of the invention, which is suitable for alleviating pain during a light-based skin treatment;
- Fig. 17 is a schematic drawing of an exemplary trap, for preventing the passage of gel to a vacuum pump;
- Fig. 18 is a schematic perspective drawing of apparatus in accordance with another embodiment of the invention, illustrating a detachable upper portion of a vacuum chamber;
- Fig. 19 is a schematic drawing of an exemplary skin cooling device, which is suitable for the apparatus of Fig. 16;
- Fig. 20 is a schematic drawing of apparatus in accordance with yet another embodiment of the invention;
- Fig. 21 is a photograph of the back of a patient, illustrating the efficacy of the hair removal treatment of the invention;

- Fig. 22 schematically illustrates a vacuum chamber which is configured to induce the expulsion of blood from a skin target to a peripheral skin area;
- Fig. 23 schematically illustrates a vacuum chamber which is configured to induce blood transfer from a peripheral skin area to a skin target;
- 5 - Figs. 24A and 24B schematically illustrate the accumulation of gel as a vacuum chamber is displaced from skin area to another;
- Fig. 25 schematically illustrates a vacuum chamber to which a vacuum is applied by means of a peristaltic pump;
- Fig. 26A is a plan view of an array of vacuum chambers and Fig. 26B is a cross sectional view thereof, taken about plane A-A of Fig. 26A;
- 10 - Figs. 27A-C illustrate the production of a vacuum chamber by a vertically displaceable cover in three stages; and
- Fig. 28 is a schematic perspective view of a sapphire transmitting element that is suitable for transmitting both light and RF waves to a skin target.

#### Detailed Description of Preferred Embodiments

15 **[0099]** The present invention is directed to apparatus which is provided with a unit for evacuating vapors, such as condensed vapors that were produced during the chilling of skin prior to the firing of the laser unit. The evacuation unit comprises a U-shaped vacuum chamber through which monochromatic or intense pulsed light passes as it is directed to a skin target, and a vacuum pump. During operation of the vacuum pump, the vacuum level within the vacuum chamber is increased by occluding a conduit of the vacuum chamber e.g. by a finger of the operator. As vacuum is applied to the skin target, skin is drawn toward the vacuum chamber and the concentration of blood vessels in the vicinity of the target increases. The added concentration of blood vessels increases the absorption of light within the tissue, and therefore facilitates treatment of a skin disorder.

25 **[0100]** Fig. 1 illustrates the propagation of an intense pulsed laser beam the wavelength of which is in the visible or near infrared region of the spectrum, i.e. shorter than 1800 nm, from the distal end of a handpiece to a skin target according to a prior art method. Handpiece 1001 comprises clear transmitting element 1002, such as a lens or a window, which transmits monochromatic beam 1007 emitted from the laser unit and impinges skin target 1004. The beam penetrates skin target 1004 and selectively impinges a subcutaneous skin structure to be thermally injured, such as collagen bundle 1005, blood vessel 1009, or hair follicle 1006. In this method, external pressure or vacuum is not applied to the skin.

30 **[0101]** Fig. 2 illustrates a prior art non-coherent intense pulsed light system from which light is fired to a skin target for e.g. treatment of vascular lesions, hair removal, or photorejuvenation. Handpiece 1010 comprises light guide 1011 which is in contact with skin target 1004. Beam 1012, which is generated by lamp 1013 and reflected from reflector 1014, is non-coherent and further reflected by the light guide walls. In some handpieces, such as those produced by Deka (Italy), a clear transmitting element is utilized, rather than a light guide. Chilling gel is often applied to the skin when such a light system is employed. In this method, external pressure or vacuum is not applied to the skin, and the handpiece is gently placed on the skin target, so as to avoid removal of the gel layer, the thickness of which is desired to remain at approximately 0.5 mm.

35 **[0102]** Fig. 3 illustrates a prior art laser system similar to those of US Patent Nos. 5,595,568 and 5,735,844, which employs an optical component 1022 at the distal end thereof in contact with skin target 1004. Pressure is applied to skin target 1004, in order to expel blood from those portions of blood vessels 1025, as schematically illustrated by the arrows, which are in the optical path of subcutaneously scattered light, thereby allowing more monochromatic light to impinge hair follicle 1006 or collagen bundle 1005. Concerning hair removal, melanin is generally utilized as an absorbing chromophore.

45 **[0103]** Fig. 4 illustrates a prior art device 1031, such as that produced by LPG (France), which is in pressing contact with skin 1033 in order to perform a deep massage of cellulite adipose layer 1037. Device 1031 is formed with a convex surface 1039 in a central region of its planar skin contacting surface 1043. Device 1031 stimulates the flow of lymphatic fluids in their natural flow direction 1038 in order to remove toxic materials from the adjoining tissue. The stimulation of lymphatic fluid flow is achieved by applying a vacuum to the interior of device 1031 so that air is sucked therefrom in the direction of arrow 1034 of the skin. The application of the vacuum draws skin toward convex surface 1039 and induces the temporary formation of skin fold 1040, which is raised in respect to adjoining skin 1033. Due to the elasticity of skin, skin fold 1040 returns to its original configuration, similar to the adjoining skin, upon subsequent movement of device 1031, while another skin fold is formed. As device 1031 is moved by hand 1036 of a masseur in direction 1044 of the device, similar to natural flow direction 1038, the lymphatic fluids flow in their natural flow direction. However, the lymphatic fluids will not flow if device 1031 were moved in a direction opposite to direction 1044. Wheels 1035 enable constant movement of device 1031.

55 **[0104]** In some cellulite massage devices, such as those produced by Deka (Italy) or the Lumicell Touch (USA), a low power continuous working infrared light source with a power level of 0.1- 2 W/cm<sup>2</sup> provides deep heating of the cellulite area and additional stimulation of lymphatic flow. Such a light source is incapable of varying the temperature by more



than 2-3 °C, since higher temperatures would be injurious to the tissue and cause hyperthermia. Consequently these massage devices are unable to attain the temperatures necessary for achieving selective thermal injury of blood vessels, hair follicles or for the smoothening of fine wrinkles. Due to the movement of the device, the amount of optical energy, e.g. by means of an optical meter, to be applied to the skin cannot be accurately determined.

[0105] Fig. 5 illustrates a prior art hair removal device, similar to the device of US Patent No. 5,735,844, which is provided with a slot 1052 within a central region of skin contacting surface 1051 of handpiece 1050. When handpiece 1050 is placed on skin surface 1058 and a vacuum is applied to the handpiece via opening 1053, skin fold 1054 is formed. A narrow slot 1052 induces formation of a correspondingly longer skin fold 1054. Optical radiation is transmitted to the two opposed sides 1056 of skin fold 1054 by a corresponding optical fiber 1055 and optical element 1057. Upon application of the vacuum, skin fold 1054 is squeezed to prevent blood flow therethrough. This device is therefore intended to reduce the concentration of blood within skin fold 1054, in order to increase illumination of melanin-rich hair shafts, in contrast with the apparatus of one embodiment of this invention by which blood concentration is increased within the slight vacuum-induced skin protrusion so as to induce increased light absorption, as will be described hereinafter. Furthermore, this prior art device, due to the reduced concentration of blood within skin fold 1054, is not suitable for treatment of vascular lesions, photorejuvenation, or the method of hair removal which is aided by the absorption of optical energy by blood vessels that surround or underly hair follicles (as opposed to the method of hair removal which is aided by the absorption of optical energy by melanin).

[0106] Although the application of a vacuum to a skin surface has been employed in the prior art to supplement skin treatments performed by means of optical energy, many significant differences between prior art apparatus for a vacuum-assisted light-based skin treatment to that of the present invention are evident:

a) The prior art application of vacuum is intended to remove smoke or vapors caused by the light-based ablation of a skin surface. By the apparatus of the present invention, in contrast, the optical energy does not interact with the skin surface, but rather is targeted to subcutaneous skin structures without producing smoke or vapors.

b) In order to remove smoke and vapors produced by a prior art light-based skin treatment, a flushing process is required whereby the produced smoke and vapors are purged and replaced by clean air. A low vacuum level is therefore generated, since if a high level vacuum were generated, the treatment handpiece would be prevented from being lifted and displaced from one skin target to another. In contrast, a high vacuum level of approximately 0 atmospheres is generated in the method of the present invention to sufficiently draw the skin into the vacuum chamber and to therefore facilitate the treatment of a skin disorder, yet the treatment handpiece may be quickly repositioned from one skin target to another.

c) Since smoke or vapor removal by means of prior art apparatus prevents the same from adhering to the distal window of a light source, the vacuum application by prior art apparatus should immediately follow each light treatment pulse. The apparatus of one embodiment of the present invention, in contrast, stimulates an increase in blood vessel concentration by applying the vacuum in order to increase light absorption, and therefore the vacuum needs to be applied prior to the firing of the treatment beam.

d) Prior art apparatus does not provide means to temporarily modulate the vacuum level. In contrast, the apparatus of the present invention has control means for modulating the applied vacuum level, by which the optical absorptivity of a skin target may be adjusted in order to effect a desired treatment.

e) Evacuation of skin ablation and of smoke or debris by means of prior art apparatus precludes employment of a protective gel layer over the skin, since the gel forms a barrier between the skin surface and the ambient air. Even if a prior art apparatus were conducive to the application of gel, no provision is made to prevent obstruction of the vacuum pump. In contrast, the apparatus of the present invention allows for the application of gel to the skin prior to a vacuum-assisted non-ablative treatment, since the light-based treatment is subcutaneous, and furthermore, provides means for preventing the obstruction of the vacuum pump.

f) With respect to apparatus of the prior art which is intended to induce blood expulsion from local skin tissue, the treatment beam is limited, to a laser beam of approximately 5 mm. If the treatment beam were significantly larger, e.g. 40 mm, blood expulsion would not be uniform and instantaneous, and therefore blood may remain in the skin tissue after a laser beam has been fired. In contrast, the apparatus of the present invention is suitable for performing skin treatments when the treatment beam is 40 mm, and furthermore is suitable for performing skin treatments by means of an IPL unit having a beam diameter which is significantly larger than that of a laser unit.

g) Prior art vacuum-assisted light-based skin treatment devices are known only to reduce the concentration of blood within a skin target, in order to increase the exposure of the skin target to the treatment light. The apparatus of the present invention, however, employs a vacuum chamber overlying the skin target, as will be described hereinafter, which does not necessarily expel blood from the epidermis of the skin target, but rather increases the blood volume fraction within the skin target.

[0107] Figs. 22 and 23 illustrate two vacuum chamber configurations, respectively, which induce different blood transfer

effects. In Fig. 22, vacuum chamber 100 is configured to induce the expulsion of blood 140 from skin target 130 to peripheral skin area 135, as indicated by the direction of the arrows, while vacuum chamber 200 of Fig. 23 is configured to induce blood transfer from peripheral skin area 210 to skin target 230, as indicated by the direction of the arrows.

**[0108]** The direction of blood transfer is dependent on the ratio of the skin target diameter to the thickness of the vacuum chamber walls. In Fig. 22, vacuum chamber 100 has thin walls 105 which serve to squeeze blood while peripheral skin area 135 slides under walls 105 as skin target 130 is drawn proximally. As walls 105 are thinner or sharper, the localized pressure under the walls is increased, resulting in a more effective squeezing of blood in the same direction as the skin sliding direction and outwardly from walls 105. On the other hand, as shown in Fig. 23, relatively thick support elements 250 of vacuum chamber 200 induce blood transfer towards skin target 230. Due to the increased thickness of support elements 250, the frictional force applied by support elements 250 onto the underlying skin surface is increased relative to that applied by walls 105 of Fig. 22, and therefore peripheral skin area 210 is prevented from sliding under support elements 250. As support elements 250 press on the underlying skin surface, albeit by a localized pressure less than applied by walls 105 of Fig. 22, the corresponding blood vessels are squeezed and blood is forced to flow towards skin target 230.

**[0109]** Fig. 6 illustrates the apparatus according to an embodiment of the invention, which is generally designated by numeral 1070. Apparatus 1070 comprises light source 1071, handpiece 1073 provided with clear transmitting element 1076 at its distal end, an evacuation unit which is designated by numeral 1090, and preferably a pressure indicator (not shown) for indicating the pressure within the vacuum chamber.

**[0110]** Evacuation unit 1090 comprises vacuum pump 1080, vacuum chamber C, and conduits 1078 and 1079 in communication with chamber C. Vacuum chamber C, which is placed on skin surface 1075, is formed with an aperture (not shown) on its distal end and is provided with a clear transmitting element 1076 on its proximate end. Vacuum chamber C is integrally formed with handpiece 1073, such that cylindrical wall 1091 is common to both handpiece 1074 and vacuum chamber C. Element 1076 is transparent to beam 1074 of intense pulsed monochromatic or non-coherent light which is directed to skin target T. Element 1076 is positioned such that beam 1074 is transmitted in a direction substantially normal to skin surface 1075 adjoining skin target T. The ratio of the maximum length to maximum width of the aperture, which may be square, rectangular, circular, or any other desired shape, ranges from approximately 1 to 4. Since the aperture is formed with such a ratio, skin target T is proximately drawn, e.g. 1 mm from skin surface 1075, and is slightly deformed, as indicated by numeral 1087, while increasing the concentration of blood in skin target T. Likewise, employment of an aperture with such a ratio precludes formation of a vacuum-induced skin fold, which has been achieved heretofore in the prior art and which would reduce the concentration of blood in skin target T.

**[0111]** Wall 1091 is formed with openings 1077 and 1084 in communication with conduits 1078 and 1079, respectively. The two conduits have a horizontal portion adjacent to the corresponding opening, a vertical portion, and a long discharge portion. Openings 1077 and 1084 are sealed with a corresponding sealing element 1093, to prevent seepage of fluid from the vacuum chamber. Conduit 1079 is also in communication with vacuum pump 1080, which draws fluid, e.g. air, thereto at subatmospheric pressures. U-shaped vacuum chamber C is therefore defined by clear transmitting element 1076 of the handpiece, slightly deformed skin surface 1087, wall 1091 and conduits 1078 and 1079.

**[0112]** A suitable light source is a pulsed dye laser unit, e.g. produced by Candela or Cynosure, for the treatment of vascular lesions, which emits light having a wavelength of approximately 585 nm, a pulse duration of approximately 0.5 microseconds and an energy density level of 10 J/cm<sup>2</sup>. Similarly any other suitable high intensity pulsed laser unit, such as a Nd:YAG, pulsed diode, Alexandrite, Ruby or frequency doubled laser, operating in the visible or near infrared region of the spectrum may be employed. Similarly, a laser unit generating trains of pulses, such as the Cynosure Alexandrite laser, the Lumenis "Quatim" IPL or Deka "Silkapiil". The emitted light is transmitted via optical fiber 1072 to handpiece 1073. Handpiece 1073 is positioned such that clear transmitting element 1076 faces skin surface 1087. Beam 1074 propagating towards slightly protruded skin surface 1087 is substantially normal to skin surface 1075.

**[0113]** Following operation of vacuum pump 1080, air begins to become evacuated from vacuum chamber C via conduit 1079. Occluding conduit 1078, such as by placing finger 1083 of an operator on its outer opening increases the level of the vacuum within chamber C to a pressure ranging from 200 to 1000 millibar. The application of such a vacuum slightly draws skin target T towards chamber C without being pressed, as has been practiced heretofore in the prior art, thereby increased the concentration of blood vessels within skin target T. The efficacy of a laser unit in terms of treatment of vascular lesions is generally greater than that of the prior art, due to the larger concentration of blood vessels in skin target T, resulting in greater absorption of the optical energy of beam 1074 within bodily tissue.

**[0114]** The operator may fire the laser following application of the vacuum and the subsequent change in color of skin target T to a reddish hue, which indicates that the skin is rich in blood vessels. The time delay between the application of the vacuum and the firing of the laser is based on clinical experience or on visual inspection of the tissue color.

**[0115]** Fig. 7 illustrates another embodiment of the present invention wherein the operation of the vacuum pump and of the pulsed laser or non-coherent light source is electronically controlled. The depth of light penetration within the tissue may be controlled by controlling the time delay between application of the vacuum and the firing of the pulsed light. If the time delay is relatively short, e.g. 10 msec, blood vessel enrichment will occur only close to the surface of

the skin at a depth of approximately 0.2 mm, while if the delay is approximately 300 msec, the blood vessel enrichment depth may be as great as 0.5-1.0 mm.

[0116] Apparatus 1170 comprises handpiece 1101, laser system 1116, evacuation unit 1190 and control unit 1119.

[0117] Laser system 1116 includes a power supply (not shown), a light generation unit (not shown), and power or energy detector 1130 for verifying that the predetermined energy density value is applied to the skin target. Handpiece 1101 held by the hand of the operator is provided with lens 1104, which directs monochromatic beam 1105 transmitted by optical fiber 1103 from laser system 1116 to skin target area 1140. Clear transmitting element 1100 defining vacuum chamber 1106 is generally in close proximity to skin surface 1142, at a typical separation H of 1-2 mm and ranging from 0.5 to 4 mm, depending on the diameter of the handpiece. The separation is sufficiently large to allow for the generation of a vacuum within chamber 1106, but less than approximately one-half the diameter of the window 1100, in order to limit the protrusion of skin target 1140 from the adjoining skin surface 1142. By limiting the separation of element 1100 from skin surface 1142 while maintaining the vacuum applied to skin target 1140, formation of a skin fold is precluded while more blood may be accumulated in a smaller skin thickness. Therefore a significant local rise in the temperature of a blood vessel, which ranges from 50-70°C, is made possible.

[0118] Evacuation unit 1190 comprises vacuum chamber 1106 which is not U-shaped, miniature vacuum pump 1109 suitable for producing a vacuum ranging from 200-1000 millibar, conduit 1107 and control valve 1111 through which subatmospheric fluid is discharged from chamber 1106, and miniature pressurized tank 1110 containing, e.g. 100 ml, which delivers air through conduit 1112 and control valve 1108 to chamber 1106. If so desired, a clear transmitting element need not be used, and vacuum chamber 1106 defined by lens 1104 will have an accordingly larger volume.

[0119] Control unit 1119 comprises the following essential elements:

a) Display 1115 of the energy density level of the monochromatic light emitted by laser system 1116 and a selector for selecting a predetermined energy density.

b) Confirmation indicator 1120 which verifies that the selected energy density is being applied to the skin. Control circuitry deactivates the laser power supply if a beam having an energy density significantly larger than the predetermined value is being fired.

c) Display 1122 concerning the pulse structure, such as wavelength, pulse duration and number of pulses in a train.

d) Control circuitry 1123 for selecting the time delay between operation of vacuum pump 1109 and laser system 1116.

e) Selector 1124 for controlling the vacuum level in vacuum chamber 1106 by means of pump 1109.

f) Control circuitry 1126 for controlling the vacuum duty cycle by regulating the operating cycle of vacuum pump 1109, the open and close time of control valve 1111, the average vacuum pressure, the vacuum modulation frequency, and the repetition rate.

g) Control circuitry 1143 for delivering fluid from positive pressure tank 1110 by controlling the duty cycle of control valve 1108.

h) Light detector 1185 for sensing whether light is impinging onto skin target 1140.

[0120] Tank 1110, in which air having a pressure ranging from 1-2 atmospheres is contained, provides a fast delivery of less than 1 msec of air into chamber 1106, as well as a correspondingly fast regulation of the vacuum level therein by first opening control valves 1108 and 1111 and activating vacuum pump 1109. After a sufficient volume of fluid, e.g. 1 ml, is delivered to chamber 1106, control valve 1108 is closed. Control circuitry 1126 and 1143 then regulate the operation of the control valves so to maintain a predetermined level of vacuum. Upon achieving the predetermined vacuum level, control circuitry 1123 fires laser system 1116 after the predetermined time delay, which may range from 1-1000 msec.

[0121] Control unit 1119 may also be adapted to increase the pressure in vacuum chamber 1106 to atmospheric pressure (hereinafter in "a vacuum release mode") following deactivation of the pulsed light beam source, to allow for effortless repositioning of the vacuum chamber to another skin target. In order to achieve a fast response time between the deactivation of the light source and the pressure increase within the vacuum chamber prior to repositioning the vacuum chamber to another skin target, light detector 1185 is employed to detect the light emitted by the treatment light source. When the light detector ceases to detect light emitted by the light source, a suitable command is transmitted to control unit 1119, whereupon the latter generates a command to open control valve 1111, in order to increase the vacuum chamber pressure. Alternatively, the vacuum within the vacuum chamber may be released by depressing a pneumatically or electrically actuated button located on the handpiece, following deactivation of the light source. Employment of a light detector which triggers the release of the vacuum in the vacuum chamber in order to allow for the speedy repositioning of the treatment handpiece has particular significance in conjunction with fast treatment systems such as the hair removal "Light Sheer" diode system produced by Lumenis, which operates at a fast rate of 1 pulse per second.

[0122] Fig. 8 illustrates apparatus 1270, which comprises a non-coherent intense pulsed light system similar to that described with respect to Fig. 2 and provided with Xe flashlamp 1201, such as one manufactured by Lumenis, Deka, Palomar, or Syneron. Reflector 1202 reflects the emitted light 1207 to light guide 1208. Distal end 1203 of light guide

1208 is separated 1-2 mm from skin surface 1242 to allow for the generation of a vacuum in vacuum chamber 1206 without compromising treatment efficacy by limiting the protrusion of the skin target from the adjoining skin surface 1242.

[0123] Figs. 15a-b illustrate another embodiment of the invention wherein apparatus 1670 comprises a vacuum chamber 1601 which is attached to intense pulsed light guide 1602. Fig. 15a schematically illustrates vacuum chamber 1601 prior to attachment to the light guide, and Fig. 15b schematically illustrates the attachment of vacuum chamber 1601 to light guide 1602. Vacuum chamber 1601 has walls 1608, side openings 1605 formed in walls 1608, and proximate cover 1612 formed with a proximate aperture 1607 having dimensions substantially equal to the cross section of light guide 1602. Attachment means 1604 facilitates the attachment of vacuum chamber 1601 to light guide 1602 or to any element adapted to protect the light guide. Attachment means 1604 preferably also seals the interface between cover 1612 and light guide 1602, to prevent the infiltration of air into vacuum chamber 1601 after the generation of a vacuum therein. Clear transmitting element 1625 of light guide 1602 also serves to prevent an increase in vacuum chamber pressure. Once vacuum chamber 1601 is attached to light guide 1602, the vacuum chamber may be placed on a selected skin surface 1603. After a vacuum is generated within chamber 1601, skin target 1606 is drawn into the interior of vacuum chamber 1601, whereupon pulsed light beam 1620 may be fired towards skin target 1606. Vacuum chamber 1601 may be advantageously attached to the distal end of any existing IPL or laser source, to convert the light source into an apparatus for enhancing the absorption of light in targeted skin structures, in accordance with the present invention. This embodiment is particularly useful when the distal end of the light source is provided with an integral skin chilling device.

[0124] Fig. 9 illustrates the placement of apparatus 1370 onto arm 1310. Apparatus 1370 comprises handpiece 1301, evacuation unit 1390, and skin chiller 1300 for cooling the epidermis of arm 1310, which is heated as a result of the impingement of monochromatic light thereon. Skin chiller 1300 is preferably a metallic plate made of aluminum, which is in contact with the epidermis and cooled by a thermoelectric cooler. The temperature of the plate is maintained at a controlled temperature, e.g. 0°C. The chilled plate is placed on a skin region adjacent to skin target 1340. The epidermis may be chilled prior to the light treatment by other suitable means, such as by the application of a gel or a low temperature liquid or gas sprayed onto the skin target.

[0125] It will be appreciated that the utilization of a U-shaped vacuum chamber 1306 for the evacuation of vapors which condense on clear transmitting element 1376 is particularly advantageous when a skin chiller in permanent contact with the handpiece outer wall is employed. Such a skin chiller results in condensation of vapors on the transmitting element that would not be evacuated without employment of an evacuation unit in accordance with the present invention. Alternatively, the skin chiller may be releasably attached to the vacuum chamber.

[0126] Fig. 10 schematically illustrates the effect of applying a subatmospheric pressure to a skin target, in accordance with the present invention, in order to enhance the absorption of light by blood vessels within the skin target. For clarity, the drawing illustrates the effect with respect to a single blood vessel; however, it should be appreciated that many blood vessels contribute to the effect of increased blood transport whereby a plurality of blood vessels are drawn to the epidermis, resulting in increased absorption of the optical energy. The protrusion of the skin target relative to the adjoining skin surface is also shown in disproportionate fashion for illustrative purposes.

[0127] The increase in light absorption within blood vessels due to the application of a vacuum in the vicinity of a skin target depends on the vacuum level, or the rate of vacuum modulation, and the skin elasticity which is reduced with increased age. As shown, blood vessel 1329 of diameter D is in an underlying position relative to vacuum chamber 1326. By applying a vacuum by means of evacuation unit 1390, blood flow is established in blood vessel 1329 in the direction of arrow M, due to a difference of pressures between points A and B closer and farther from vacuum chamber 1326, respectively. If the blood vessel is a vein, the flow will be established in only one direction, due to the influence of the corresponding vein valve.

[0128] According to the Hagen-Poiseuille equation concerning the flow of viscous fluids in tubes, the discharge from a tube and consequently the duration of flow therethrough depends on a pressure gradient along the tube, the fourth power of the diameter of the tube, and the length thereof. For example, diameters of 100 microns are common for capillaries adjacent to the papillary dermis at a depth of approximately 200 microns and 500-micron blood vessel diameters can be found in the hair bulb at a depth of 3 mm. A typical blood vessel length is approximately 1-2 cm. It will be appreciated that although the blood vessel diameters generally increase with depth, the pressure gradient along the blood vessel is smaller at deeper layers of the skin. As a result, for a given pressure, such as the application of a zero millibar vacuum, each depth from the skin surface corresponds to a characteristic time response for being filled by blood. As a result, modulation of the vacuum by opening and closing control valve 1111 (Fig. 7) controls the flow of blood through blood vessels and consequently controls the degree of light absorption by a blood vessel at a given depth from skin surface 1342. In a realistic situation wherein a plurality of blood vessels are located within a skin target, each skin layer is characterized by a different modulation frequency which typically ranges between 100 Hz for upper layers and 1 Hz for the deep layers under the hair follicles. By opening control valves 1108 and 1111 (Fig. 7) by a varying frequency, the operator may modulate the vacuum applied to the skin target and thereby vary the blood richness of different skin layers.

[0129] The operator typically determines an instantaneous modulation frequency of control valves 1108 and 1111 by

visually inspecting the skin target and viewing the degree of redness thereat in response to a previous control valve modulation frequency. In addition to improving the treatment efficacy, an increased degree of redness within the skin target advantageously requires a lower energy density of intense pulsed light for achieving blood coagulation or blood heating resulting in the heating of the surrounding collagen. Alternatively, an erythema, i.e. skin redness, meter, e.g. produced by Courage-Hazaka, Germany, may be employed for determining the degree of redness, in order to establish the necessary energy density for the treatment.

[0130] For example, a modulation frequency as high as 40 Hz or the firing of a Dye laser unit approximately 1/40 seconds after application of a vacuum may be necessary for applications of port wine stains. In contrast, a delay of approximately a half second for fine wrinkle removal and of approximately 1 second for hair removal may be needed for a depth of 1-3 mm under the skin surface.

[0131] Fig. 11 illustrates the concentration of a plurality of blood vessels 1329 in a skin target 1340, which results in the increase of redness of skin and enhanced absorption of light with respect to the hemoglobin absorption spectrum and scattering properties of skin. Light absorption is enhanced by a larger number of blood vessels per unit volume due to the correspondingly larger number of light absorbing chromophores. The beneficial effect of vacuum assisted absorption by Dye lasers or any yellow light, which is strongly absorbed by hemoglobin, is more pronounced on white or yellow skin not rich in blood vessels, such as that of smokers. Such types of skin suffer from enhanced aging and require photorejuvenation, the efficacy of which is improved with the use of the present invention. Enhanced absorption of light is also advantageously achieved when infrared lasers and intense pulsed light sources are employed.

[0132] Fig. 12 is a photograph illustrating the treatment of a fine wrinkle 1401 by means of a vacuum assisted handpiece according to the current invention, which was taken one-half of a second after the application of a vacuum. Circles 1402-4 indicate the sequential treatment spots. The color in the circle 1403 has changed.

[0133] Fig. 23 illustrates another embodiment of the invention, by which blood vessel concentration within a skin target is increased by selecting the thickness of the supporting elements of the vacuum chamber. Vacuum chamber 200 placed on skin target 230 comprises cover 205, clear transmitting element 215 centrally retained within cover 205, relatively thin annular leg 240 having a thickness of  $T_2$  positioned below cover 205 at the outer periphery thereof, relatively thick annular support element 250 of thickness  $T_1$  separated from leg 240 and positioned below cover 205 at skin area 210 adjoining skin target 230, and conduits 255 formed within cover 205 by which the vacuum is applied to the vacuum chamber. Each conduit 255 is provided with an inner inlet 282 and an outer inlet 284. Each inner inlet 282 communicates with volume  $V_1$  interior to annular support element 250 and each outer inlet 284 communicates with volume  $V_2$ , which has a significantly smaller volume than volume  $V_1$  and is formed between support element 250 and surrounding annular leg 240.

[0134] When a vacuum is applied to vacuum chamber 200, the pressure differential between the surrounding ambient air pressure and the generated vacuum within the vacuum chamber urges vacuum chamber 200 to be in pressing relation with the skin adjoining skin target 230. The resultant force associated with the pressure differential acts on both legs 240 and on support elements 250. Since a vacuum is applied onto the two sides of support element 250 via volumes  $V_1$  and  $V_2$ , the resultant force transmitted to underlying skin area 210 by support element 250 produces a substantially uniform squeezing pressure. By virtue of thin vacuum volume  $V_2$ , legs 240 serve as a means to stabilize vacuum chamber 200, which is particularly useful on a skin area that is not completely planar, such as in the vicinity of a bone.

[0135] The wide area pressure applied by support element 250 onto skin area 210 directs the expelled blood towards skin target 230 as well as towards leg 240. Air evacuated from volume  $V_1$  through inner inlets 282 causes skin target 230 to be proximally drawn and blood to be transported from peripheral skin area 210 towards skin target 230. Support element 250 therefore induces inward blood transport from peripheral skin areas 210 to skin target 230, as represented by arrow 272, resulting in a significant increase in the blood volume fraction within skin target 230. After the blood concentration within skin target 230 has sufficiently increased, light beam 260 is suitable for treating vascular lesions with a wavelength well absorbed by the blood vessels within the skin target, and therefore an energy density less than that of the prior art is fired. The depth of light absorption within skin target 230 can be controlled by changing the thickness  $T$  of support elements 250.

[0136] Air evacuated from volume  $V_2$  through a corresponding outer inlet 284 causes skin area 290 underlying corresponding volume  $V_2$  to be drawn drawn proximally. Skin area 290 is then pressed by the edge of support element 250 so that blood, as represented by arrow 292, is outwardly transported from support element 250 to leg 240. By inducing outward transport of blood, the blood volume fraction and therefore the depth of light absorption within skin target 230 may be further controlled.

[0137] It will be appreciated that the blood concentration within skin target 230 can be increased solely by the pressure applied by support element 250, without use of legs 240. Likewise, support elements 1325, 1345, and 1502 illustrated in Figs. 10, 11, and 13, respectively, induce blood transport towards the skin target without need of additional legs.

[0138] Fig. 13 illustrates apparatus 1570 which increases blood vessel concentration within a skin target without use of a handpiece. Apparatus 1570 comprises evacuation unit 1590 having a transparent vacuum chamber 1501 and a clear transmitting element 1506, which is made of a thin, transparent polymer such as polycarbonate or of glass, which

is transparent to visible or near infrared light. Vacuum chamber 1501 has a diameter of 5-20 mm and a height of approximately 1-3 mm, in order to avoid excessive protrusion of the skin. Chamber 1501 is preferably cylindrical, although other configurations are also suitable. A soft silicon rim (not shown) is adhesively affixed to the periphery of the chamber 1501, in order to provide good contact with skin surface 1542. Conduit 1503 in communication with control valve 1504 allows for the evacuation of vacuum chamber 1501 by means of a miniature vacuum pump (not shown) and control unit 1505. After chamber 1501 is placed on skin target 1540, pulsed beam 1508 from any existing intense pulsed laser or light source 1509 which operate in the visible or near infrared regions of the spectrum may propagate therethrough and effect treatment of a skin disorder. Vacuum chamber 1501 and conduit 1503 are preferably disposable. When vacuum chamber 1501 is disposable, clear transmitting element 1506 is insertable within a suitable groove formed within the housing of vacuum chamber 1501. Vacuum chamber 1501 may be hand held or may be releasably attachable to the handpiece of light source 1509. When hand held, vacuum chamber 1501, control unit 1505, and a display (not shown) may be integrated into a single device. The treatment may therefore be performed with the use of two hands, one hand, e.g. hand 1530, holding the integrated vacuum chamber device by means of handle 1531 and the other holding the treatment light source. The advantage of this apparatus is its low price and its ability to interact with any intense pulsed laser or non-coherent light source which is already installed in a health clinic.

**[0139]** The absorption of visible intense pulsed light in blood vessels when vacuum is applied to a skin target may be enhanced by the directing electromagnetic waves to the skin target. Radio frequency waves operating in the range of 0.2-10 Mhz are commonly used to coagulate tiny blood vessels. The alternating electrical field generated by a bipolar RF generator, such as produced by Elman, USA or Synron, Canada, follows the path of least electrical resistance, which corresponds to the direction of blood flow within blood vessels. A monopolar RF may also be employed, such as manufactured by Thermage, USA.

**[0140]** Fig. 14 illustrates apparatus 1870 which comprises intense pulsed laser or intense pulsed light source 1821, RF source 1811, and evacuation unit 1890. Evacuation unit 1890 comprises vacuum chamber 1801, which is placed on skin surface 1802 to be treated for vascular lesions, miniature vacuum pump 1805, and control valve 1804 for regulating the level of the vacuum in chamber 1801. Clear transmitting element 1806 is positioned in such a way that beam 1820 generated by light source 1821 propagates therethrough and impinges skin surface 1802 at an angle which is substantially normal to the skin surface.

**[0141]** RF source 1811 is a bipolar RF generator which generates alternating voltage 1807 applied to skin surface 1802 via wires 1808 and electrodes 1809. Alternatively, the RF source is a monopolar RF generator with a separate ground electrode. Electric field 1810 generally follows the shape of blood vessels 1813, which are the best electrical conductors in the skin. Due to the concentration of blood vessels 1813 in the epidermis, the depth of which below skin surface 1802 depending on the vacuum level and the frequency of vacuum modulation, the combined effect of optical energy in terms of beam 1820 and pulsed RF field 1810 heats or coagulates the blood vessels. Control valve 1804 is regulated by means of control unit 1812. A first command pulse 1 of control unit 1812 controls valve 1804 and a second command pulse 2 controls a delayed radio frequency pulse as well as a delayed light source pulse.

**[0142]** When a vacuum chamber is placed on a skin target, the apparatus provides an additional advantage in terms of the capability of alleviating pain that is normally caused during e.g. the treatment of hair with intense pulsed monochromatic or non-coherent light.

**[0143]** As shown in Fig. 16, apparatus 1970 is configured so as to bring skin target 1960, when a vacuum is applied, in contact with clear transmitting element 1906, e.g. made from sapphire, which is secured to the proximate end of vacuum chamber 1901. The Applicant has surprisingly discovered that the immediate sharp pain which is normally sensed during a light-based skin treatment is alleviated or eliminated when a skin target contacts the clear transmitting element. The level of the applied vacuum is suitable for drawing skin target 1960 towards vacuum chamber 1901 by a slight protrusion of K, e.g. 2-4 mm, with respect to adjoining skin surface 1965, a distance which is slightly greater than the gap between clear transmitting element 1906 and the distal end of outer wall 1924 of vacuum chamber 1901. During generation of pulsed beam 1908 from any suitable intense pulsed laser or light source propagating through clear transmitting element 1906, whereby hair follicles 1962 located under the epidermis of skin target 1960 are treated by the generated optical energy, skin target 1960 is drawn to be in contact with clear transmitting element 1906. As skin target 1960 is drawn by the vacuum into vacuum chamber 1901 and contacts clear transmitting element 1906 by means of the resulting proximally directed force, the pain signals generated by the nervous system during the heating of hair follicles 1962, or of any other suitable targeted skin structure, of the patient are inhibited. Accordingly, the synchronization of an optimal delay between the application of the vacuum and firing of the light treatment pulse is a key factor in pain reduction, in order to ensure that skin target 1960 is in contact with clear transmitting element 1906 for a sufficiently long nerve inhibiting duration when pulsed beam 1908 is fired. Pain reduction is noticeable with use of this apparatus even when the energy level of the light directed to skin target 1960 is increased, an effect which normally causes an increase in immediate sharp pain.

**[0144]** Vacuum chamber 100 illustrated in Fig. 22 is also configured to alleviate the pain resulting from the firing of light beam 160 onto skin target 130. When a vacuum is applied onto vacuum chamber 100 via conduits 155, skin target



130 is drawn and contacts clear transmitting element 115. Instead of sensing immediate sharp pain during impingement of each treatment pulse with a skin area 136 of skin target 130, the magnitude of proximally directed force F resulting from the applied vacuum causes nerve 138 surrounding a corresponding hair bulb and extending to skin area 136 to be pressed onto clear transmitting element 115 for a sufficient duration to inhibit the pain sensation. Light beam 160 is of a wavelength which is well absorbed by hair follicles 139. By optimizing the time delay between application of the vacuum and the firing of light beam 160, the pain sensation is sufficiently inhibited and the energy density of light beam 160 need not be decreased.

[0145] The apparatus for alleviating pain during vacuum-assisted light-based treatments of the skin may include a control device (not shown) for adjusting the vacuum level generated by the vacuum pump, as well as the time delay between the application of the vacuum and the firing of light beam. The control device preferably has a plurality of finger depressable buttons, each of which is adapted to set the vacuum pump and light source at a unique combination of operating conditions so as to generate a predetermined vacuum level within vacuum chamber 100 and to result in a predetermined time delay between the operation of the vacuum pump and the firing of light beam 160, and a display to indicate which button was depressed. The apparatus may also comprise control valves in electrical communication with the control device for evacuating air into vacuum chamber during a vacuum applying mode and for introducing air therein during a vacuum release mode; respectively. The health professional is aware of the anticipated pain level that a patient generally senses when one of these buttons is depressed. If the pain threshold of a patient is relatively low or if the application of the vacuum by the vacuum chamber onto the skin target is annoying, the health professional may change the combination of operating conditions by depressing a different button. Alternatively, the pain threshold of a patient may be objectively determined by an electrical measurement of a muscle reflex in response to pain.

[0146] As skin target 130 is pressed onto clear transmitting element 115 during the application of the vacuum, blood is displaced from skin target 130 to peripheral skin area 135. Although the blood fraction volume in peripheral skin area 135 is increased, the latter is nevertheless liable to be damaged by the treatment light, which may diffuse subcutaneously from skin target 130 to skin area 135. To counteract the potential thermal injury to skin area 135, heat absorbing gel (not shown in the figure) is applied to skin target 130 prior to application of the vacuum and is subsequently squeezed to peripheral skin area 135 by means of transmitting element 115. The displaced gel therefore advantageously protects peripheral skin area 135 from being injured by subcutaneously diffused treatment light.

[0147] The apparatus may be advantageously provided with means to prevent the obstruction of the vacuum chamber conduits by heat releasing gel applied to the skin target prior to the treatment. As shown in Figs. 24A and 24B, gel 185 is squeezed to the periphery of vacuum chamber 180 after application of a vacuum. When vacuum chamber 180 is displaced from skin area 190 to skin area 192, further gel is squeezed and accumulates, as shown in Fig. 24B. The gel is eventually aspirated into the vacuum chamber conduits, causing a significant risk of obstruction thereto when a large-diameter treatment beam normally associated with an IPL unit is used and necessitating the employment of a correspondingly large-diameter vacuum chamber. Without employing means to prevent passage of the gel, a large quantity of gel is liable to be drawn through the conduits and to the vacuum pump, eventually resulting in the malfunction of the latter and in less efficacious treatments. Also, aspirated gel tends to contaminate the vacuum chamber, and the cleaning or sterilization of the vacuum chamber prior to the treatment of another patient is difficult.

[0148] Referring back to Fig. 16, vacuum chamber 1901 has two passageways 1930 through which air is evacuated therefrom. Each passageway 1930, which is in fluid communication with the interior of vacuum chamber 1901, is defined by outer wall 1924, vertical portion 1926, and cylindrical horizontal wall 1930 connected to both outer wall 1924 and vertical portion 1926. The distal end of vertical portion 1926 is connected to clear transmitting element 1906, vertically spaced above, and interiorly spaced from, the distal end of outer wall 1924 placed on skin surface 1965, and is connected to vertical portion 1926 of passageway 1930. The top of horizontal passageway wall 1930 is vertically spaced above outer wall 1924, and vacuum chamber 1901 is therefore considered to be U-shaped. Each horizontal wall 1930 terminates with an opening 1917, which is separated from the distal end of outer wall 1924 by P and is laterally separated from centerline 1969 of vacuum chamber 1901 by J. While the gel may be drawn by the applied vacuum or may laterally slide from skin target 1960 after being pressed by clear transmitting element 1906, dimensions P and J are selected so as to ensure that the volume of the passageways 1930 and of the chamber interior between wall 1924 and the adjacent surface of drawn skin target 1960 is sufficiently large to prevent the obstruction of corresponding opening 1917 by gel 1963. For example, a vacuum chamber having a height K of 2 mm, a wall opening diameter of 3 mm, a separation P of 10 mm from the opening to the distal end of the wall, and a lateral separation J of 20 mm from the vacuum chamber centerline to the opening is sufficient to prevent obstruction of the opening by gel.

[0149] Fig. 17 illustrates another arrangement for preventing vacuum pump suction of gel. The arrangement includes trap 1920, conduit 1940 through which gel and air are drawn from the vacuum chamber to trap 1920, and conduit 1945 through which air is drawn from trap 1920 to the vacuum pump, all of which may be disposable. Air evacuated from the vacuum chamber through opening 1917 flow through conduits 1940 and 1945 until introduced to the inlet port of the vacuum pump. The gel which is evacuated from the vacuum chamber collects within trap 1920. Trap 1920 is periodically emptied so that the accumulated gel does not rise above the inlet of conduit 1945. Trap 1920 and conduits 1940 and



1945 are preferably made from a plastic hydrophilic material, to urge the gel to cling to the walls thereof rather than to be drawn through the conduits to the vacuum pump. As shown, gel 1966 clings to the walls of conduit 1940 and gel 1967 is collected on the bottom of trap 1920. The conduits may be suitably sized to prevent the passage of gel to the vacuum pump. For example, the diameter of conduit 1940 at the vacuum wall opening is 30 mm and narrows to a diameter of 10 mm at the discharge to trap 1920, and the diameter of conduit 1945 at the inlet side is 5 mm and is 10 mm at the discharge side in the vicinity of the the vacuum pump inlet port.

[0150] Other arrangements for preventing vacuum pump suction of gel may also be employed. For example, the gel may be bound to a suitable ion exchange resin introduced into trap 1920 and thereby be prevented from being drawn through conduit 1945. If so desired, a filter may be provided at the inlet of conduits 1940 and 1945.

[0151] Alternatively, gel may be prevented from exiting the vacuum chamber by increasing the diameter of conduit 1940 at the vacuum wall opening. Consequently, the inwardly directed force acting on the gel which has laterally slid from a drawn skin target by means of the atmospheric air introduced to the vacuum chamber via conduit 1940 during a vacuum release mode is sufficient to prevent the gel from exiting the vacuum chamber. A hydrophobic coating, such as silicon or teflon, may be applied onto the vacuum chamber walls, so that the gel will be prevented from adhering to the vacuum chamber walls, particularly during a vacuum release mode. Instead of adhering to the vacuum chamber walls, the gel falls to the skin surface. Advantageously, gel is therefore not transported to another skin target during the repositioning of the handpiece, but rather assumes the shape of the distal end of the vacuum chamber walls. If the distal end of the vacuum chamber walls is circular, for example, the gel that falls to the skin surface during a vacuum release mode is also circular, indicating to the health professional that is supervising the treatment that the given skin surface has already been impinged by the treatment light.

[0152] In Fig. 18, apparatus 1980 comprises a vacuum chamber having a detachable upper portion, so that the gel retained by the vacuum chamber interior walls may be removed therefrom, such as by dissolving the gel with salt or with any other suitable dissolving agent. Apparatus 1980 comprises upper portion 1983 having an open central area, clear transmitting element 1984 attached to upper portion 1983, vacuum chamber walls 1981, vacuum chamber cover 1982 perpendicular to walls 1981 and suitably sized so as to support upper portion 1983, and a plurality of attachment clips 1987 pivotally connected to a corresponding vacuum chamber wall 1981 for detachably securing upper portion 1983 to vacuum chamber cover 1982. Thin compliant sealing element 1988 is preferably attached to the periphery of vacuum chamber cover 1982, to prevent infiltration of atmospheric air into the vacuum chamber. Conduit 1940 is shown to be in communication with the interior of the vacuum chamber.

[0153] Fig. 25 illustrates another embodiment of apparatus for preventing the obstruction of vacuum chamber conduits by heat releasing gel during vacuum-assisted light-based treatments of the skin. Apparatus 400 comprises vacuum chamber 420, peristaltic pump 430, vacuum controller 440, control valve 450, and micro-switch 460.

[0154] The vacuum applying mode is initiated upon transmission of signal 445 to controller 440, following which peristaltic pump 430 is activated. Peristaltic pump 430 comprises hose 442 connected to conduit 425 in communication with the interior of vacuum chamber 420 and rotatable hub 446, from which a plurality of shoes and/or rollers 448 (referred to hereinafter as "pressing elements") radially extend. As hub 446 rotates, the pressing elements sequentially squeeze a different region of hose 442 and a volume of fluid entrapped by two adjacent pressing elements is thereby forced to flow unidirectionally through hose 442 by a positive displacement action towards end 449 thereof. Consequently, when peristaltic pump 430 is activated, air is drawn from the interior of vacuum chamber 420 to generate a vacuum therein ranging from 0-1 atmospheres. If a considerable amount of gel 405 accumulates within the periphery of vacuum chamber 420, the gel is also forced to flow within hose 442 without causing any obstruction to the latter. The gel that is discharged from end 449 of hose 442 falls onto skin surface 410, indicating that an adjoining skin target 415 has undergone a light-based treatment.

[0155] Micro-switch 460, or any other suitable skin contact detector, is adapted to sense the placement of the handpiece or of vacuum chamber chamber 420, onto skin target 415. Micro-switch 460 generates signal 445 upon sensing the placement of vacuum chamber 420 on skin target 415. Control valve 450 is triggered by a light detector (not shown), which generates signal 455 upon detecting the termination of the light-based treatment pulse 470. Control valve 450 is opened after the generation of signal 455, to introduce atmospheric pressure air 452 to the interior of vacuum chamber 420 via passageway 456 and to thereby initiate the vacuum release mode. Signal 455 is also transmitted to controller 440, to deactivate peristaltic pump 430. The described automatic operation of peristaltic pump 430 therefore prevents the patient from suffering pain during the associated treatment. If so desired, the operation of peristaltic pump 430 may be manually overridden.

[0156] It will be appreciated that a peristaltic pump or a contact detector may be employed in conjunction with any other embodiment of the invention.

[0157] In another embodiment, the vacuum pump is an air pump. When air is evacuated from the vacuum chamber, a piston (not shown) which is normally closed by a spring is opened to allow air to be aspirated. During the vacuum release mode, the piston is set to its original position, returning air to the vacuum chamber and any aspirated gel to the skin surface.

**[0158]** Figs. 27A-C illustrate another embodiment of the invention wherein a vacuum pump is not needed for vacuum-assisted light-based treatments of the skin. Apparatus 600 comprises a vertically displaceable cover 610 to which clear transmitting element 615 is secured, chamber walls 620 in which vertically displaceable cover 610 is mounted, and sealing element 625 which is secured to the outer periphery of cover 610. Chamber walls 620 surround, and are of a similar shape as, cover 610.

**[0159]** When cover 610 is in its lowermost position, as shown in Fig. 27A, the cover is flush with skin surface 630 on which is applied a layer of gel 635. In this position, air is prevented from infiltrating between cover 610 and skin target 630, e.g. by means of a sealing element externally affixed to walls 620. When a proximally directed force represented by arrows 652 is applied to cover 610, as shown in Fig. 27B, the cover is raised while sealing element 625 resiliently contacts walls 620. Apparatus 600 is configured such that distal displacement of cover 610 is prevented after having been raised, without application of a subsequent distally directed force. While cover 610 is raised, a vacuum chamber 640 is produced internally to chamber walls 620, due to the increased volume between cover 610 and skin surface 630 while air is prevented from infiltrating therein. The vacuum generated within vacuum chamber 640 as a result of the proximal displacement of cover 610 ranges from 0-1 atmospheres and is suitable for drawing skin target 650 towards the displaced cover 610 as shown, in order to be subsequently impinged by a treatment pulse. When a distally directed force represented by arrows 654 is applied to cover 610 following the light-based treatment, as shown in Fig. 27C, cover 610 returns to its lowermost position in preparation for displacement to the next skin target. Aeration tube 675 in communication with a manually operated or control valve (not shown) may be employed to quicken distal displacement of cover 610 during a vacuum release mode by introducing atmospheric air to vacuum chamber 640 upon conclusion of the skin target treatment.

**[0160]** Proximally directed force 652 or distally directed force 654 may be generated manually by means of handles (not shown) attached to cover 610, or electrically by means of a plurality of solenoids 670 and/or by means of a spring assembly 660 deployed around the periphery of cover 610, as well known to those skilled in the art to achieve balanced displacement of the cover. Solenoids 670 are mounted such that one side of a solenoid is mechanically connected to displaceable cover 610 and the other side thereof is connected to a chamber wall 620. When electrical actuation of cover 610 is employed, command 608 generated by skin contact sensor 460 (Fig. 25) is transmitted to spring assembly 660 or solenoids 670 after a predetermined time delay following contact between cover 610 and skin surface 630, causing cover 610 to be proximally displaced upward with a proximally directed lifting force 652 comparable to that of a piston. By properly controlling solenoids 670, height H of the drawn skin target 650 relative to the adjoining skin surface 630 can be adjusted. Height H of the drawn skin is generally increased as the treatment spot is increased. For example, height H may be 2 mm for a treatment spot of 40 mm, while height H may be 0.5 mm for a treatment spot of 3 mm. Alternatively, height H may be adjusted to ensure that skin target 650 contacts clear transmitting element 615 for pain alleviation.

**[0161]** At times, a sufficiently high vacuum level for effecting a light-based treatment may not be produced within vacuum chamber 640, due to a malfunction. If a health professional notices that the distance between skin target 650 and clear transmitting element 615 is greater than a predetermined distance for effective treatment with an IPL or laser, the automatic control of cover 610 may be overridden. By reversing the direction of current within solenoids 670, one-time distally directed force 678 may be generated which urges cover 610 towards skin surface 630.

**[0162]** When the distal end of the treatment light source is positioned on chamber walls 620, cover 610 has a relatively low weight of approximately 50 gm. However, if the treatment handpiece is positioned on cover 610 such that the combined weight of the cover and handpiece is approximately 1 kg, the capacity of solenoids 670 needs to be increased, in order to raise both the cover and handpiece and to produce a vacuum within chamber 640.

**[0163]** Apparatus 600 advantageously provides low power consumption and increased compactness. When the handpiece is positioned on chamber walls 620, solenoids 670 are energized by a battery without need of draining wall current and only when cover 610 is needed to be vertically displaced. The energy requirement for raising cover 610 to a height of 2 mm is approximately 0.5 J for a typical 500-pulse large area treatment on the back or legs. Therefore an inexpensive 1.5 V battery is suitable for more than 1000 treatments.

**[0164]** Apparatus 600 also advantageously prevents accumulation of gel. When skin target 650 is drawn during a vacuum applying mode as shown in Fig. 27B, gel 635 is displaced to a peripheral skin area within vacuum chamber 640. However, when cover 610 returns to its original lowermost position as shown in Fig. 27C, skin target 650 is retracted. Gel 635 is then substantially uniformly spread underneath cover 610, due to the pressure applied by cover 610. Similarly when apparatus 600 is repositioned to another skin target, gel 635 does not accumulate.

**[0165]** The proximally directed force may be supplemented by means of a vacuum pump, which may be needed if an excessive amount of gel is applied to skin surface 630 or if it desired to indicate that skin target 650 has undergone a light-based treatment as described hereinabove.

**[0166]** Fig. 28 illustrates another embodiment of the invention which is suitable for pain alleviation. Apparatus 700 comprises vacuum chamber 705 and IPL treatment light source 710, e.g. one produced by Syneron USA, which is provided with an RF source at the distal end thereof in the form of two electrodes 720. When clear transmitting element

725 of vacuum chamber 705 is made of sapphire, which has electrical insulating properties, the RF waves are prevented from propagating to skin target 735. To allow sapphire to be a suitable transmitting element for apparatus 700, two metallic conducting electrodes 730 are welded in two slits, respectively, formed in the sapphire transmitting element 725. Electrodes 730 are positioned to be within the propagation path of electrodes 720 integrally formed in light source 710. Suitable means, such as a magnetic rod (not shown), may be used to ensure the quick centering of light source 710 with respect to electrodes 730 of sapphire transmitting element 725. During application of the vacuum, skin target 740 contacts the sapphire transmitting element 725 and electrodes 730 transmit RF waves to skin target 740.

[0167] Fig. 19 illustrates an exemplary skin cooling device which is suitable for the pain alleviating apparatus of the present invention. Since the vacuum chamber is configured so as to ensure that a skin target contacts the clear transmitting element when a vacuum is applied, as described hereinabove, skin cooling is optimized when clear transmitting element 1906 is directly cooled. Accordingly, thermally conducting plate 1975, which is cooled by thermoelectric chiller 1979, contacts clear transmitting element 1906, in order to conduct the heat generated by the treated skin target 1960 from the clear transmitting element. The treatment handpiece is provided with chiller 1979 so as to prevent an increase in temperature of the epidermis, which may be damaged if the skin is relatively dark, e.g. Fitzpatrick skin type 4-6. In order to improve the compactness of the skin cooling device, plate 1975 is positioned obliquely with respect to clear transmitting element 1906 without interfering with the propagation of light beam 1908. It will be appreciated that pain alleviation is achieved by application of a vacuum, which brings the skin in contact with the clear transmitting element, and not by means of the chiller. As described in Example 8 hereinbelow, pain relief was noticeable during experimentation performed in conjunction with vacuum-assisted, light-based treatments without employment of a skin chiller.

[0168] The clear transmitting element may be alternatively cooled by applying a low temperature spray, such as produced by Dermachill, USA, to conducting plate 1975 or by means of a chilling liquid flowing over the conducting plate.

[0169] In Fig. 20, apparatus 1990 comprises a thin polycarbonate layer 1994, e.g. having a thickness of 10 microns, attached to the distal face of clear transmitting element 1993 and transparent to the treatment light directed to skin target 1960. Vacuum chamber 1991 is suitably sized and the applied vacuum level is sufficient to draw skin target 1960 to be in pressing contact with polycarbonate layer 1994. Polycarbonate layer 1994 is sufficiently thin to conduct heat from skin target 1960 to clear transmitting element 1993, is sufficiently soft to provide good mechanical matching between skin target 1960 and clear transmitting element 1993, and also provides good optical matching therebetween.

[0170] As described hereinabove, applying a vacuum to the vacuum chamber may either increase or decrease the blood volume fraction within a skin target, depending on a selected configuration of the vacuum chamber. Accordingly, a health professional may employ two differently configured vacuum chambers, each of which is releasably attachable to the same light source handpiece, in order to effect two distinct types of vacuum-assisted light-based treatment, respectively, with a minimum delay to the patient. Thus a single light source and a single vacuum pump may be used for both treatment of vascular lesions by increasing blood concentration within a skin target and for painless hair removal.

[0171] In summation, Table I below tabulates the main differences between prior art vacuum-assisted-light-based treatment methods, by which ablated skin and vaporous debris are evacuated from a skin target, and that of the present invention:

Table I

	Present Invention	Prior Art Smoke Evacuators
Treatment Depth	Subcutaneous	Skin surface
Light source	Non-ablative, 400-1800 nm	Ablative, above 1800 nm
High Vacuum Level (approximately 0 atm)	Yes	No; evacuated air is replaced by fresh air
Automatic Release of Vacuum, to Allow Displacement of Treatment Handpiece	Yes; by means of control unit	Not necessary due to low vacuum level
Contact between Skin and Clear Transmitting Element	Yes; for pain alleviation	No
Suitable for Employment of Gel	Yes	No
Vacuum-Assisted Pain Alleviation	Yes	No
Enhanced Skin Redness	Yes	No

Table continued

	Present Invention	Prior Art Smoke Evacuators
5 Suitable for Non- Ablative IPL and Nd: YAG, Dye, Alexandrite, Ruby, and Diode Lasers	Yes	No; Suitable for Ablative Lasers

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[0172] Figs. 26A-B illustrate another embodiment of the invention by which a vacuum chamber need not be repositioned from one skin target to another. Fig. 26A is a schematic plan view of the apparatus and Fig. 26B is a cross sectional view thereof. As shown, array 500 of vacuum chambers is embodied by a single flat sheet 505, e.g. disposable and produced from low cost, transparent or translucent molded silicon, which is placed on skin surface 520 and formed with a plurality of vacuum chambers 510. The interior of each vacuum chamber 510 is defined by a bottom which is coplanar with bottom edge 515 of sheet 505, two side walls 522 extending proximally from bottom edge 515, and top edge 522 separated distally from upper surface 525 of sheet 505. A clear transmitting element 540 corresponding to each vacuum chamber 510 is secured to sheet 505, directly above top edge 522 of the vacuum chamber. Clear transmitting element 540 may be an inexpensive thin polycarbonate plate or a diffuser. The bulk material of sheet 505 is also formed with a plurality of conduits 530, each of which in communication with a corresponding vacuum chamber 510 and through which air is evacuated from the corresponding vacuum chamber. The distance between adjacent vacuum chambers 510 is sufficiently small to allow light which has diffused from the interior of each chamber to treat a skin area located underneath a corresponding conduit 530. Each conduit 530 branches into portions 532 and 534, wherein all conduit portions 532 are in communication with a vacuum pump (not shown) and all conduit portions 534 are in communication with a source of compressed air (not shown).

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[0173] Array 500 advantageously allows a large-area skin surface, such as of an arm or leg, to be treated by a light source. The treatment light source is sequentially directed to each vacuum chamber 510. Following propagation of the light through a selected vacuum chamber in order to treat a corresponding skin target, the light source may be quickly moved or glided to another skin target without having to move a vacuum chamber and overcoming the force which urges it to the skin surface. Since a vacuum chamber is not displaced, gel is similarly not moved and does not accumulate. Consequently, there is no need to provide means for preventing obstruction of gel within the vacuum pump.

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[0174] Array 500 is also provided with at least one contact detector (not shown), which triggers a signal to activate the vacuum pump. When the contact detector senses the placement of array 500 on a skin surface, the vacuum pump is activated, and the air from all vacuum chambers 510 is evacuated simultaneously. The health professional then sequentially directs the light source to each vacuum chamber 510. Following completion of the treatment for the entire skin surface, the light source is deactivated and then the vacuum pump is deactivated. Alternatively, each vacuum chamber is provided with a contact detector, two control valves to control the passage of fluid through conduits portions 532 and 534, respectively, and light detector (all of which are not shown). When a treatment handpiece is placed on a transmitting element 540, the corresponding contact detector transmits a signal to activate the vacuum pump, open the control valve which regulates the fluid passage through the corresponding conduit portion 532, and then activates the light source. Upon completion of the light treatment, the light source is deactivated after a predetermined period of time or is manually deactivated. The light detector transmits a signal to close the control valve which regulates the fluid passage through the corresponding conduit portion 532 and to open the control valve which regulates the fluid passage through the corresponding conduit portion 534, in order to release the vacuum. This cycle is repeated for all vacuum chambers 510.

#### 45 Example 1

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[0175] An experiment was performed to determine the time response of skin erythema following application of a vacuum onto various skin locations. A pipe of 6 mm diameter was sequentially placed on a hand, eye periphery, arm, and forehead at a subatmospheric pressure of approximately 100 millibar. The skin locations were selected based on the suitability for treatment: the hands and eye periphery for wrinkle removal, arm for hair removal, and forehead for port wine stain treatment. The vacuum was applied for the different periods of time of 1/10, 1/2, 1, 2, 3 seconds and then stopped. The erythema level and erythema delay time were then measured.

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[0176] The response time of the hand and eye periphery was 1/2 sec, the response time of the arm was 1 second and the response time of the forehead was 1/2 second. Accordingly, the experimental results indicate that the necessary delay between the application of the vacuum and firing of the laser or intensified pulsed light is preferably less than 1 second, so as not to delay the total treatment time, since the repetition rate of most laser or intensified pulsed light sources is generally less than 1 pulse /sec.

[0177] The erythema delay time was less than 1 second, and therefore the experimental results indicate that patients

will not sense appreciable aesthetic discomfort following treatment in accordance with the present invention.

### Example 2

**[0178]** An intense pulsed light system comprising a broad band Xe flashlamp and a cutoff filter for limiting light transmission between 755 nm and 1200 nm is suitable for aesthetic treatments, such that light delivered through a rectangular light guide is emitted at an energy density of 20 J/cm<sup>2</sup> and a pulse duration of 40 milliseconds, for hair removal with respect to a treated area of 15 X 45 mm.

**[0179]** While efficacy of such a light system for the smoothening of fine wrinkles, i.e. photorejuvenation, is very limited by prior art devices, due to the poor absorption of light by blood vessels at those wavelengths, enhanced light absorption in targeted skin structures in accordance with the present invention would increase the efficacy.

**[0180]** A transparent vacuum chamber of 1 mm height is preferably integrally formed with a handpiece through which intense pulsed light is directed. A diaphragm miniature pump, such as one produced by Richly Tomas which applies a vacuum level of 100 millibar, is in communication with the chamber and a control valve is electronically opened or closed.

When the control valve is opened, the pressure in the vacuum chamber is reduced to 100 millibar within less than 10 milliseconds. As a result of the application of vacuum, the skin slightly protrudes into the vacuum chamber at an angle as small as 1/15- 1/45 radian (height divided by size of skin target) and a height of 1 mm. Blood is drawn into the drawn skin target, which achieves a much pinker hue and therefore has a higher light absorbence. The increased redness of the skin increases the light absorption by a factor of 3. As a result, the efficacy of the aforementioned light system is similar to that of a prior art system operating at 60 Joules/cm<sup>2</sup>, which is known to provide adequate results in wrinkle removal procedures. At energy density levels as high as 20 J/cm<sup>2</sup>, it is preferable to chill the epidermis in order to avoid a risk of a burn. Epidermis chilling is accomplished by means of an aluminum plate, which is chilled by a thermoelectric chiller. The plate is in contact with the skin and chills the skin just before the handpiece is moved to the chilled skin target, prior to treatment.

**[0181]** The invention has thereby converted an intense pulsed light device for hair removal into an efficient photorejuvenation device as well.

### Example 3

**[0182]** An Nd:YAG laser operating at 1064 nm, 40 milliseconds pulse duration, and energy density of 70 J/cm<sup>2</sup> is suitable for prior art hair removal having a spot size of 7 mm. By prior art hair removal, absorption of light in the hair shaft melanin is limited, with a contributory factor in hair removal being attributed to the absorption of light by blood in the hair follicle bulb zone. Since the energy density level of 70 J/cm<sup>2</sup> is risky to the epidermis of dark skin, it would be preferable to operate the laser at 40 J/cm<sup>2</sup>.

**[0183]** A vacuum chamber is preferably integrally formed with a handpiece through which intense pulsed light is directed, at a distance of 1 mm from the skin target. A vacuum is applied to the skin target for 2 seconds. The blood concentration near the follicle bulb and in the bulge at a depth of 4 and 2 mm, respectively, is increased by a factor of 2. As a result the laser is operated with the same efficacy at energy levels closer to 40 J/cm<sup>2</sup> and is much safer.

### Example 4

**[0184]** A Dye laser emitting light at a wavelength of 585 nm, with a spot size of 5 mm and pulse duration of 1 microsecond, is used by prior art methods for treatment of vascular lesions, such as telangectasia, and port wine stains, at an energy density level ranging from 10-15 J/cm<sup>2</sup> and for the smoothening of wrinkles at an energy density level of 3 -4 J/cm<sup>2</sup>. Some disadvantages of the prior art method are the purpura that is often produced on the skin during vascular treatments and the very large number of treatments (more than 10) which are necessary for the smoothening of wrinkles.

**[0185]** By applying a controlled vacuum to a vacuum chamber in contact with a skin target, having either a moderate vacuum level of approximately 600 millibar or a vacuum which is modulated at a frequency of 10 Hz for 1 seconds prior to the firing of the laser, the efficacy of the laser is enhanced. Consequently it is possible to treat vascular lesions at 7 J/cm<sup>2</sup> without creating a purpura and to remove wrinkles with a much smaller number of treatments (5).

### Example 5

**[0186]** A prior art diode laser operated at 810 nm or a Dye laser is suitable for treating vascular rich psoriatic skin, wherein the treated area per pulse is approximately 1 cm<sup>2</sup>. By employing a vacuum chamber attached to the distal end of the handpiece of either of these lasers, blood is drawn to the lesion and treatment efficacy is improved. The vacuum may be applied for 2 seconds prior to firing the laser beam.

**Example 6**

[0187] A deep penetrating laser, such as a pulsed diode laser at 940 nm, an Nd:YAG laser, or an intense pulsed light source operating at an energy density of 30 J/cm<sup>2</sup>, is suitable for thermally damaging a gland, when a vacuum chamber is attached to the distal end of the handpiece thereof. When vacuum is applied for a few seconds, e.g. 1-10 seconds, above a gland such as a sweat gland, excessive blood is drawn into the gland. After the pulsed laser beam is directed to the skin, the absorption of the laser beam by the drawn blood generates heat in the gland, which is thereby damaged. It is therefore possible to more efficiently thermally damage glands with a laser or intense pulsed light source when vacuum is applied to the skin.

**Example 7**

[0188] By placing a vacuum chamber on a skin target in accordance with the present invention prior to the firing of an intense pulsed light source, the treatment energy density level for various types of treatment is significantly reduced with respect to that associated with prior art devices. The treatment energy density level is defined herein as the minimum energy density level which creates a desired change in the skin structure, such as coagulation of a blood vessel, denaturation of a collagen bundle, destruction of cells in a gland, destruction of cells in a hair follicle, or any other desired effects.

[0189] The following is the treatment energy density level for various types of treatment performed with use of the present invention and with use of prior art devices:

- a) treatment of vascular lesions, port wine stains, telangiectasia, rosacea, and spider veins with light emitted from a dye laser unit and having a wavelength of 585 nm: 5-12 J/cm<sup>2</sup> (present invention), 10-15 J/cm<sup>2</sup> (prior art);
- b) treatment of vascular lesions, port wine stains, telangiectasia, rosacea, and spider veins with light emitted from a diode laser unit and having a wavelength of 940 nm: 10-30 J/cm<sup>2</sup> (present invention), 30-40 J/cm<sup>2</sup> (prior art);
- c) treatment of vascular lesions with light emitted from an intense pulsed non-coherent light unit and having a wavelength of 570-900 nm: 5-20 J/cm<sup>2</sup> (present invention), 12-30 J/cm<sup>2</sup> (prior art);
- d) treatment of vascular lesions with light emitted from a KPP laser unit manufactured by Laserscope, USA, and having a wavelength of 532 nm: 4-8 J/cm<sup>2</sup> (present invention), 8-16 J/cm<sup>2</sup> (prior art);
- e) photorejuvenation with light emitted from a dye laser unit and having a wavelength of 585 nm: 2-4 J/cm<sup>2</sup> and requiring 6 treatments (present invention), 2-4 J/cm<sup>2</sup> and requiring 12 treatments (prior art);
- f) photorejuvenation with light emitted from an intense pulsed non-coherent light unit and having a wavelength ranging from 570-900 nm: 5-20 J/cm<sup>2</sup> (present invention), approximately 30 J/cm<sup>2</sup> (prior art);
- g) photorejuvenation with a combined effect of light emitted from an intense pulsed non-coherent light unit and having a wavelength ranging from 570-900 nm and of a RF source: 10 J/cm<sup>2</sup> for both the intense pulsed non-coherent light unit and RF source (present invention), 20 J/cm<sup>2</sup> for both the intense pulsed non-coherent light unit and RF source (prior art);
- h) hair removal with light emitted from a Nd:YAG laser unit and having a wavelength of 1604 nm: 25-35 J/cm<sup>2</sup> (present invention), 50-70 J/cm<sup>2</sup> (prior art);
- i) porphyrin-based photodynamic therapy with light emitting diodes delivering blue light (420 nm), orange light (585 nm), or red light (630 nm) for a treatment duration ranging from 10 msec to 10 min: 5-20 J/cm<sup>2</sup> (present invention), 20-30 J/cm<sup>2</sup> (prior art).

**Example 8**

[0190] A vacuum chamber made of polycarbonate having a length of 50 mm, a width of 25 mm, a height of 3 mm, and a clear transmitting element made of sapphire was used during the treatment of unwanted hairs of 5 patients with an intense pulsed light system which emitted energy in the spectral band of 670-900 nm. A thin layer of gel at room temperature having a thickness of 0.5 mm was applied to a skin target. The suction openings had a diameter of 1 mm and were formed in the vacuum chamber walls at a height of 0.5 mm below the clear transmitting element, in order to prevent the obstruction of the openings by gel or by the drawn skin. A small canister serving as a gel trap was provided intermediate to the fluid passage between the vacuum chamber and the vacuum pump, to prevent gel from being drawn to the inlet port of the vacuum pump. A vacuum level of 500 mmHg was generated within the vacuum chamber and caused the skin target to be drawn in contact with the clear transmitting element.

[0191] An intense pulsed light system having a treatment beam length of 40 mm and width of 15 mm was fired with an energy density of 16 - 20 J/cm<sup>2</sup> and a pulse duration of 30-40 milliseconds. One patient underwent a back hair removal treatment, wherein areas of the back were treated as a control without application of a vacuum onto the skin surface and other areas were treated while a vacuum was applied to the skin surface. The other patients underwent a hair

removal treatment on their legs, chest and abdomen such that a vacuum was applied to some areas, while the treatment of an adjacent area was not vacuum assisted, as a control. For all five patients, a skin chiller was not employed.

[0192] Fig. 21 is a photograph which illustrates two back areas 1985 and 1986, respectively, of one of the patients two months after being treated for hair removal. A vacuum was not applied to the skin surface of back area 1985, while a vacuum was applied to the skin surface of back area 1986. As shown, both back areas remained hairless two months after treatment.

[0193] The pain sensation of the patients was categorized into five levels: Level 0 indicating that pain was not felt at all, Level 5 indicating that pain was intolerable after a few laser shots whereby a patient grimaced and uncontrollably reacted after each shot, Level 1 indicating that the treatment was sensed but without pain, and Levels 2, 3, and 4 indicating an increasing level of pain. All of the patients consistently suffered Pain Level 3-5 when a vacuum was not applied, and the pain was alleviated (Level 2) or was completely prevented (Level 1 or 0) when a vacuum was applied. Pain alleviation was found to be dependent on the time delay between the application of the vacuum and the firing of the intense pulsed light. Pain alleviation was sensed when the intense pulsed light was fired at least 1.5 seconds after application of the vacuum onto the skin surface.

#### Example 9

[0194] A patient undergoing a hair removal treatment was tested for pain sensitivity. An intense pulsed Diode laser (Light Sheer, Lumenis) operating at 810 nm was employed. A vacuum chamber made of polycarbonate having a length of 40 mm, a width of 15 mm, a height of 3 mm, and a clear transmitting element made of sapphire was used. A thin layer of gel at room temperature having a thickness of 0.5 mm was applied to a skin target. The suction openings had a diameter of 1 mm and were formed in the vacuum chamber walls at a height of 0.5 mm below the clear transmitting element. A small canister serving as a gel trap was provided intermediate to the fluid passage between the vacuum chamber and the vacuum pump, to prevent gel from being drawn to the inlet port of the vacuum pump.

[0195] When a vacuum was not applied to the skin target and the light source operated at an energy density of 42 J/cm<sup>2</sup> and a pulse duration of 30 milliseconds, the patient sensed a Pain Level of 5. When a vacuum level of 500 mmHg was generated within the vacuum chamber causing the skin target to be drawn in contact with the clear transmitting element and the light source operated at an energy density of 42 J/cm<sup>2</sup> and a pulse duration of 30 milliseconds, the patient sensed a considerably reduced Pain Level of 2. This reduced pain level during the vacuum assisted treatment was found to be equivalent to the mild pain sensed when the light source operated at an energy density of only 26 J/cm<sup>2</sup> and a pulse duration of 30 milliseconds and a vacuum was not applied to the skin target.

[0196] While some embodiments of the invention have been described by way of illustration, it will be apparent that the invention can be carried into practice with many modifications, variations and adaptations, and with the use of numerous equivalents or alternative solutions that are within the scope of persons skilled in the art, without departing from the spirit of the invention or exceeding the scope of the claims.

#### Claims

1. An apparatus for vacuum-assisted light-based skin treatments, comprising:
  - a) a non-ablative intense pulsed monochromatic or non-coherent light source;
  - b) a vacuum chamber placeable on a skin target which has an opening on the distal end thereof and provided with a clear transmitting element on the proximate end thereof, said transmitting element being transparent or translucent to light generated by said source and directed to said skin target;
  - c) means for applying a vacuum to said vacuum chamber, the level of the applied vacuum suitable for drawing said skin target to said vacuum chamber via said opening; and
  - d) means for preventing influx of air into vacuum chamber during a vacuum applying mode.
2. The apparatus according to claim 1, wherein the vacuum applying means comprises a vacuum pump.
3. The apparatus according to claim 2, wherein the vacuum applying means further comprises at least one control valve and control means for controlling operation of the vacuum pump, the at least one control valve, and the light source, said control means being suitable for firing the light source after a first predetermined delay ranging from approximately 0.5 sec to approximately 4 seconds following operation of the vacuum pump, for increasing the pressure in the vacuum chamber to atmospheric pressure following deactivation of the light source to allow for effortless repositioning of the vacuum chamber to a second skin target, for verifying that a desired energy density level of the light is being directed to the skin target, and for deactivating the light source if the energy density level



is significantly larger than said desired level, said control means being selected from the group of electronic means, pneumatic means, electrical means, and optical means and being actuated by means of a finger depressable button positioned on a light treatment handpiece.

- 5 4. The apparatus according to claim 1, wherein influx of air into the vacuum chamber during a vacuum applying mode is prevented by means of a control valve and control circuitry.
5. The apparatus according to claim 1, wherein the wavelength of the light ranges from 400 to 1800 nm, the pulse duration of the light ranges from 10 nanoseconds to 900 msec, the energy density of the light ranges from approximately 2 to approximately 150 J/ cm<sup>2</sup>, and the level of applied vacuum within the vacuum chamber ranges from approximately 0 to approximately 1 atmosphere.
- 10 6. The apparatus according to claim 1, wherein the vacuum chamber is connected to, or integrally formed with, a proximately disposed handpiece through which light propagates towards the skin target, and the vacuum chamber optionally has a proximate cover formed with an aperture which is attachable to a handpiece having an integral clear transmitting element.
- 15 7. The apparatus according to claim 5, wherein the light source is selected from the group of Dye laser, Nd:YAG laser, Diode laser, light emitting diode, Alexandrite laser, Ruby laser, Nd:YAG frequency doubled laser, Nd:Glass laser, a non-coherent intense pulse light source, and a non-coherent intense pulse light source combined with an RF source, the light is suitable for hair removal, collagen contraction, photorejuvenation, treatment of vascular lesions, treatment of sebaceous or sweat glands, treatment of warts, treatment of pigmented lesions, treatment of damaged collagen, treatment of acne, treatment of warts, treatment of keloids, treatment of sweat glands, and treatment of psoriasis, and the vascular lesions are selected from the group of port wine stains, telangiectasia, rosacea, and spider veins.
- 20 8. The apparatus according to claim 1, wherein the clear transmitting element is separated from the adjoining skin surface by a gap ranging from 0.5 to 50 mm and is suitable for transmitting the light in a direction substantially normal to a skin surface adjoining the skin target.
- 30 9. The apparatus according to claim 1, wherein the vacuum chamber has at least one suction opening and is provided with a rim for sealing the peripheral contact area between the skin surface adjoining the skin target and a vacuum chamber wall, the vacuum being applied to the vacuum chamber via said at least one suction opening.
- 35 10. The apparatus according to claim 1, wherein the vacuum chamber is U-shaped.
11. The apparatus according to claim 3, wherein the increase in vacuum chamber pressure is triggered by means of a light detector which transmits a signal to the control means upon sensing a significant decrease in optical energy generated by the light source or after a second predetermined delay, following deactivation of the light source.
- 40 12. The apparatus according to claim 1, wherein the width of a treatment spot per pulse of the light is greater than 5 mm or ranges from 15 to 50 mm.
- 45 13. The apparatus according to claim 2, wherein the vacuum pump is a peristaltic pump for drawing air and gel from the interior of the vacuum chamber via a hose connected to a conduit in communication with the interior of the vacuum chamber or is an air pump.
- 50 14. The apparatus according to claim 3, further comprising a skin contact detector for sensing the placement of the vacuum chamber onto the skin target and for generating a first signal to activate the vacuum pump following placement of the vacuum chamber onto the skin target, wherein the control valve is opened following generation of a second signal by means of a light detector which is adapted to sense termination of the light directed to the skin target, atmospheric pressure air thereby being introduced to the interior of the vacuum chamber, said second signal also being suitable for deactivating the vacuum pump.
- 55 15. The apparatus according to claim 2, further comprising an array of vacuum chambers placeable on a skin surface, wherein said array is formed from a single sheet made of material which is transparent or translucent to the light, said sheet is formed with a plurality of conduits for air evacuation such that each of said conduits is in communication with a corresponding vacuum chamber, the distance between adjacent vacuum chambers is sufficiently small to

allow light which has diffused from the interior of each chamber to treat a skin area located underneath a corresponding conduit, and each conduit branches into first and second portions which are in communication with the vacuum pump and with a source of compressed air, respectively.

5 16. The apparatus according to claim 15, wherein each vacuum chamber is provided with a contact detector for triggering a signal to activate the vacuum pump, two control valves to control the passage of fluid through the corresponding first and second conduits portions, respectively, and a light detector which generates a signal to introduce compressed air through the corresponding second conduit portion upon sensing the termination of the light directed to the skin target or the first conduit portions are arranged such that the air from all vacuum chambers is evacuated simultaneously upon activation of the vacuum pump.

10 17. The apparatus according to claim 1, wherein the vacuum applying means comprises:

- a) a vertically displaceable cover to which the clear transmitting element is secured;
- 15 b) chamber walls which surround, and are of a similar shape as, said cover, a vacuum being generated within a vacuum chamber defined by the volume between said cover, said walls, and the skin target upon proximal displacement of said cover relative to said walls; and
- c) an aeration tube for introducing atmospheric air to the vacuum chamber during a vacuum release mode, said aeration tube being in communication with a valve which is actuated upon conclusion of a skin target treatment,

20 wherein the means for preventing influx into the vacuum chamber is a sealing element which is secured to the outer periphery of the cover and resiliently contacts the chamber walls, wherein a proximally directed force or distally directed force is generated by any means selected from the group of a plurality of solenoids, a spring assembly, and a pneumatic device, or a combination thereof, which are deployed around the periphery of the cover and connected to the walls,

25 wherein the proximally directed force is controllable so as to adjust the height of the drawn skin target relative to the adjoining skin surface and is optionally supplemented by means of a vacuum pump.

30 18. The apparatus according to claim 17, wherein the solenoids are energized by a 1.5 V battery.

35 19. The apparatus according to any of claims 1 to 14, further comprising means for preventing passage of skin cooling gel to the vacuum applying means which comprises a trap, a first conduit through which gel and air are drawn from the vacuum chamber to said trap, a second conduit through which air is drawn from said trap to the vacuum pump, and optionally a filter at the inlet of said first and second conduits; a detachable vacuum chamber upper portion having an open central area, a clear transmitting element attached to said upper portion, vacuum chamber walls, a vacuum chamber cover perpendicular to said walls and suitably sized so as to support said upper portion, and a plurality of attachment clips pivotally connected to a corresponding vacuum chamber wall for detachably securing said upper portion to said vacuum chamber cover, detachment of said upper portion allowing removal of gel retained within the vacuum chamber interior; a hydrophobic material to which vacuum chamber walls are coated; or a vacuum chamber configured such that at least one suction opening is sufficiently spaced above the distal end of a vacuum chamber wall and from the centerline of the vacuum chamber so as to prevent obstruction of the at least one suction opening by gel and drawn skin upon application of the vacuum.

40 20. The apparatus according to claim 19, wherein the trap is suitable for the introduction therein of an ion exchange resin with which the gel is boundable.

45 21. The apparatus according to claim 19, comprising indication means that the skin target has undergone a light-based treatment by means of gel which is discharged from an end of the hose onto a skin surface during a vacuum applying mode or by means of gel which falls to the skin surface during a vacuum release mode in the shape of the distal end of the vacuum chamber walls.

50 22. The apparatus according to any of claims 1 to 18, further comprising means for skin cooling, said skin cooling means being adapted to reduce the rate of temperature increase of the epidermis at the skin target and the level of the applied vacuum being suitable for evacuating condensed vapors which are produced within the gap between the clear transmitting element and the skin target and condense on the clear transmitting element during the cooling of skin,

55 wherein the skin cooling means is a metallic plate positionable on the skin surface adjoining the skin target and in abutment with the vacuum chamber on the external side thereof or in contact with the clear transmitting element,

said plate being cooled by means of a thermoelectric cooler; a polycarbonate layer transparent to the directed light which is attached to the distal face of the clear transmitting element; or a gel, a low temperature liquid or gas applied onto the skin target.

- 5 23. The apparatus according to any of claims 1 to 18, wherein the apparatus is suitable for alleviating or preventing pain caused by a non-ablative light-based treatment of a targeted skin structure, wherein the gap separating the clear transmitting element from the skin surface adjoining the skin target and the magnitude of the proximally directed force resulting from the applied vacuum in combination are suitable for drawing the skin target to the vacuum chamber via the opening on the distal end of the vacuum chamber until the skin target  
10 contacts the clear transmitting element for a duration equal to the first predetermined delay, whereby pain signals generated by the nervous system during the treatment of the skin structure are alleviated or prevented, wherein the control means is suitable for firing the light source after the first predetermined delay, following operation of the vacuum applying means, and is suitable for controlling the vacuum level generated by the vacuum applying means,  
15 wherein the control means has a plurality of finger depressable buttons, each of which being adapted to set the vacuum applying means and light source at a unique combination of operating conditions so as to generate a predetermined vacuum level within the vacuum chamber and to fire the light source after a predetermined time delay following the operation of the vacuum applying means.
- 20 24. The apparatus according to any of claims 1 to 18, further comprising means to stabilize the vacuum chamber on a substantially non-planar skin surface.
- 25 25. The apparatus according to any of claims 1 to 22 and 24, wherein the vacuum chamber has at least one support element suitable for inducing an increase in the concentration of blood and/or blood vessels within a predetermined depth below the skin surface of the skin target and is releasably attachable to a treatment light handpiece.
26. The apparatus according to any of claims 1 to 25, wherein the vacuum chamber is one-hand graspable by means of a handle connected thereto.
- 30 27. An apparatus for controlling the depth of light absorption by blood vessels under a skin surface, comprising:
  - a) a vacuum chamber placed on a skin target which is formed with an aperture on the distal end thereof and provided with a clear transmitting element on the proximate end thereof, said transmitting element being transparent or translucent to intense pulsed monochromatic or non-coherent light directed to said skin target and  
35 suitable for transmitting the light in a direction substantially normal to a skin surface adjoining said skin target;
  - b) means for applying a vacuum to said vacuum chamber, the level of the applied vacuum suitable for drawing said skin target to said vacuum chamber via said aperture; and
  - c) means for inducing an increase in the concentration of blood and/or blood vessels within a predetermined depth below the skin surface of said skin target, optical energy associated with the directed light being absorbed  
40 within said predetermined depth and suitable for thermally injuring or treating predetermined skin structures located at said depth.
- 45 28. The apparatus according to claim 27, wherein the means for inducing an increase in the concentration of blood and/or blood vessels within a predetermined depth below the skin surface of said skin target is a means for modulating the applied vacuum.
- 50 29. The apparatus according to claim 27, wherein the means for inducing an increase in the concentration of blood and/or blood vessels within a predetermined depth below the skin surface of said skin target is at least one support element positioned at a skin area adjoining the skin target and having a thickness suitable for inducing an increase in the concentration of blood and/or blood vessels within said predetermined depth, and optionally comprising at least one leg having a thickness considerably less than the at least one support element and positioned at the periphery of the vacuum chamber, said at least one leg being separated from an adjacent support element, the at least one support element being adapted to urge blood expelled by said at least one leg towards the skin target.
- 55 30. The apparatus according to claim 27, which is suitable for drawing the skin target approximately 1 mm from the adjoining skin surface, wherein the maximum protrusion of the drawn skin from the adjoining skin surface is limited by the clear transmitting element.

31. The apparatus according to claim 28, wherein the frequency of vacuum modulation ranges from 0.2 to 100 Hz.
32. The apparatus according to claim 27, further comprising a control unit for controlling operation of the vacuum applying means and light source, for controlling operation of at least one control valve in communication with the vacuum chamber, for firing the light after a predetermined delay ranging from approximately 10 msec to approximately 1 second following application of the vacuum, and for electronically modulating the vacuum.
33. The apparatus according to claim 27, wherein the duration of vacuum application to the vacuum chamber is less than 2 seconds.
34. The apparatus according to claim 27, wherein the light emitted from the light source has any wavelength band from 400 nm to 1800 nm, wherein the treatment energy density level for treatment of vascular lesions, port wine stains, telangiectasia, rosacea, and spider veins with light emitted from a dye laser unit and having a wavelength of 585 nm ranges from 5 to 12 J/cm<sup>2</sup>, wherein the treatment energy density level for treatment of vascular lesions, port wine stains, telangiectasia, rosacea, and spider veins with light emitted from a diode laser unit and having a wavelength of 940 nm ranges from 10 to 30 J/cm<sup>2</sup>, wherein the treatment energy density level for treatment of vascular lesions with light emitted from an intense pulsed non-coherent light unit and having a wavelength of 570 to 900 nm ranges from 5 to 20 J/cm<sup>2</sup>, wherein the treatment energy density level for photorejuvenation with light emitted from a dye laser unit and having a wavelength of 585 nm ranges from 1 to 4 J/cm<sup>2</sup>, wherein the treatment energy density level for photorejuvenation with light emitted from an intense pulsed non-coherent light unit and having a wavelength of 570 to 900 nm ranges from 5 to 20 J/cm<sup>2</sup>, wherein the treatment energy density level for photorejuvenation with a combined effect of light emitted from an intense pulsed non-coherent light unit and having a wavelength ranging from 570 to 900 nm and of a RF source is approximately 10 J/cm<sup>2</sup> for both the intense pulsed non-coherent light unit and RF source, wherein the treatment energy density level for hair removal with light emitted from a Nd:YAG laser unit and having a wavelength of 1604 nm ranges from 25 to 35 J/cm<sup>2</sup>, wherein the treatment energy density level for porphyrin-based photodynamic therapy with light emitting diodes delivering light at a wavelength of 420 nm, 585 nm, or 630 nm ranges from 5 to 20 J/cm<sup>2</sup>.
35. The apparatus according to any of claims 27 to 34, further comprising a pulsed radio frequency (RF) source for directing suitable electromagnetic waves at a frequency ranging from 0.2 to 10 MHz to the skin target, wherein the RF source is a bipolar RF generator which generates alternating voltage applied to the skin surface via wires and electrodes or is a monopolar RF generator, wherein the control unit is suitable for transmitting a first command pulse to the at least one control valve and a second command pulse to both the light source and RF source.
36. The apparatus according to claim 32, further comprising an erythema sensor for measuring the degree of skin redness induced by the vacuum applying means, wherein the control unit is suitable for controlling, prior to firing the light source, the energy density of the light emitted from the light source, in response to the output of the erythema sensor.
37. The apparatus according to claim 32, further comprising a skin contact detector for sensing the placement of the vacuum chamber onto the skin target, the control unit being suitable for activating the vacuum applying means in response to a signal transmitted by said skin contact detector.
38. The apparatus according to claim 32, further comprising a light detector for sensing the termination of the light directed to the skin target, the control unit being suitable for regulating a control valve in response to a signal transmitted by said light detector so as to introduce atmospheric pressure air to the interior of the vacuum chamber.
39. The apparatus according to claim 27, further comprising an array of vacuum chambers placeable on a skin surface, wherein the array is formed from a single sheet made of material which is transparent or translucent to the light, said sheet being formed with a plurality of conduits for air evacuation such that each of said conduits is in communication with a corresponding vacuum chamber.
40. The apparatus according to any of claims 27 to 39, further comprising means for skin cooling, said skin cooling means adapted to reduce the rate of temperature increase of the epidermis at the skin target.

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41. The apparatus according to any of claims 27 to 39, further comprising means for preventing passage of skin cooling gel to the vacuum applying means.

5 42. The apparatus according to any of claims 27 to 41, wherein the vacuum chamber is releasably attachable to a treatment light handpiece.

43. The apparatus according to any of claims 27 to 42, wherein the vacuum chamber is one-hand graspable by means of a handle connected thereto.

10 44. The apparatus according to any of claims 27 to 43, further comprising means to stabilize the vacuum chamber on a substantially non-planar skin surface.

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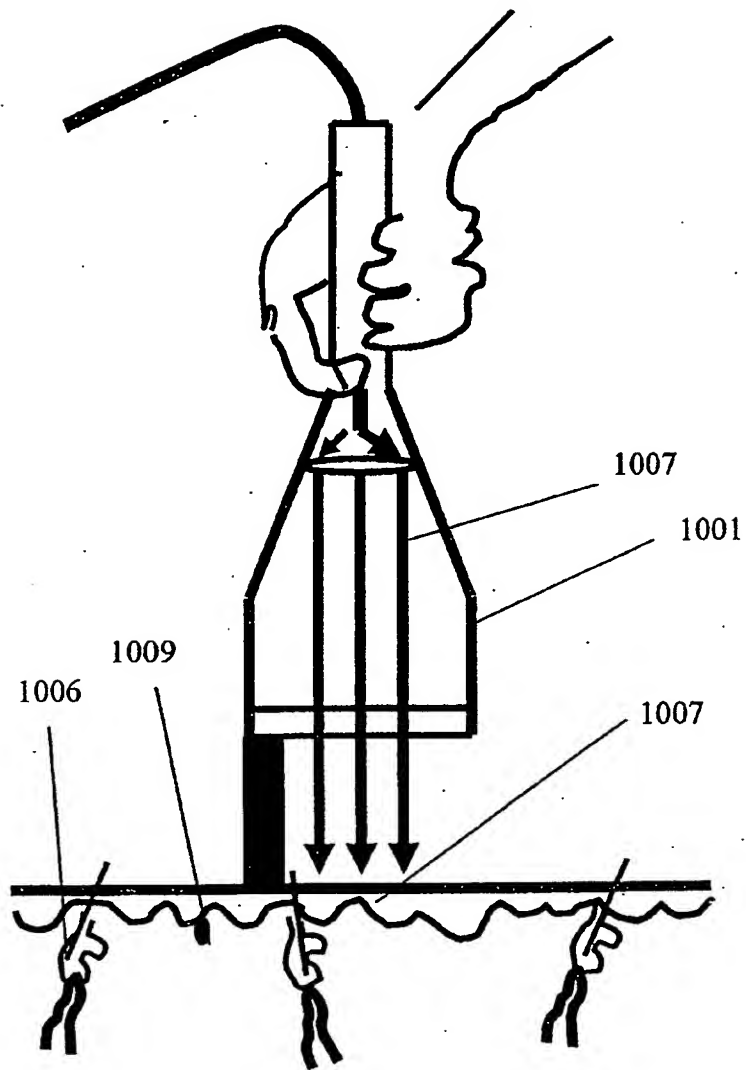


Fig. 1  
PRIOR ART

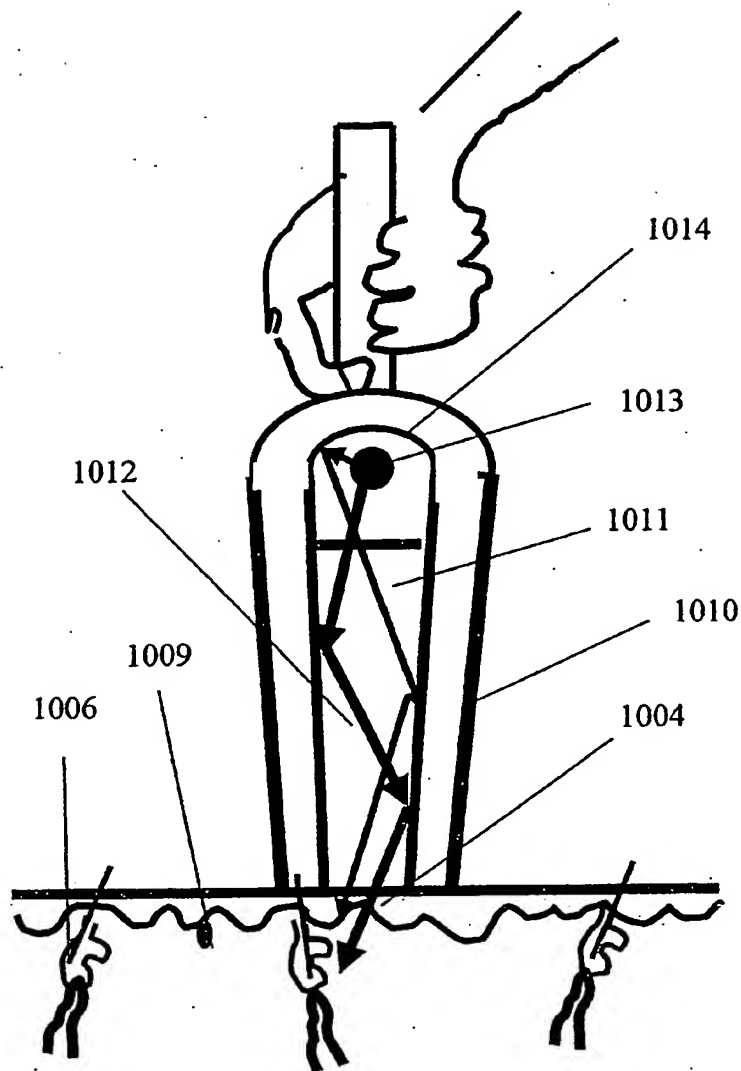


Fig. 2  
PRIOR ART



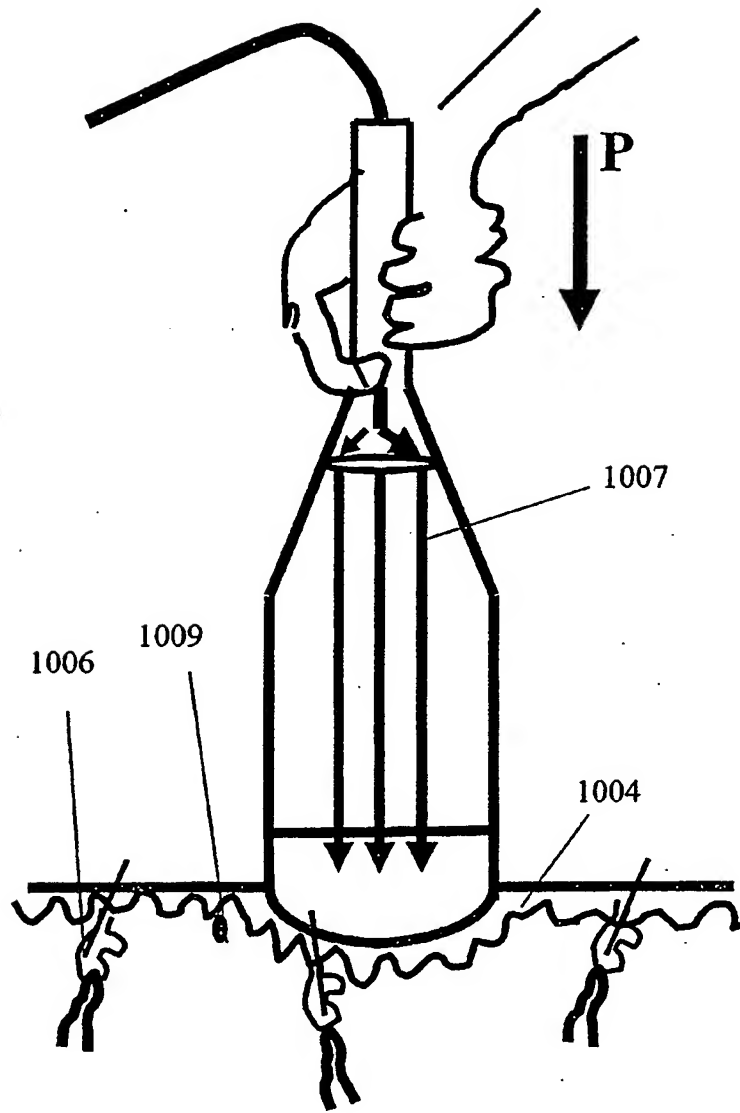


Fig. 3  
PRIOR ART

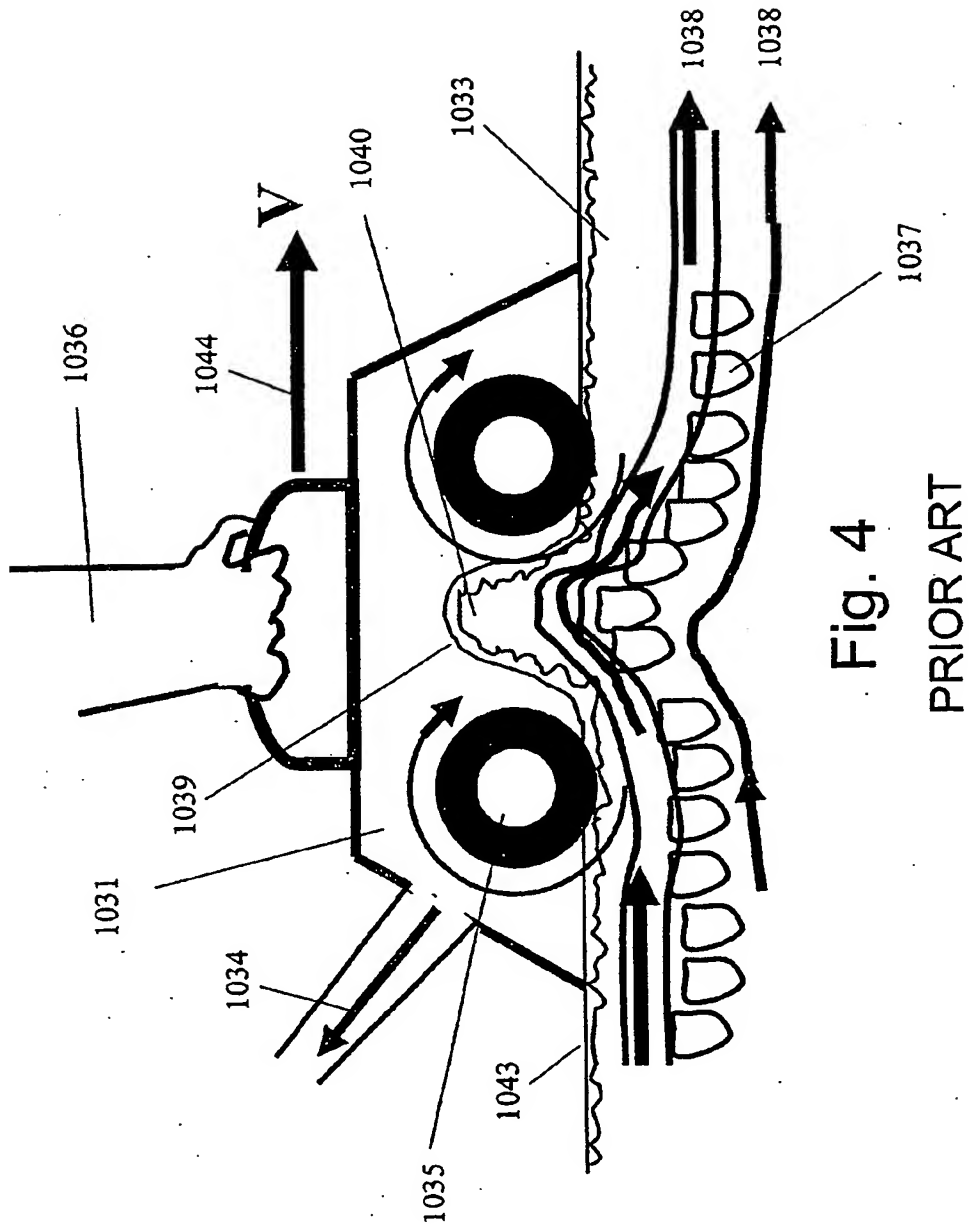


Fig. 4  
PRIOR ART

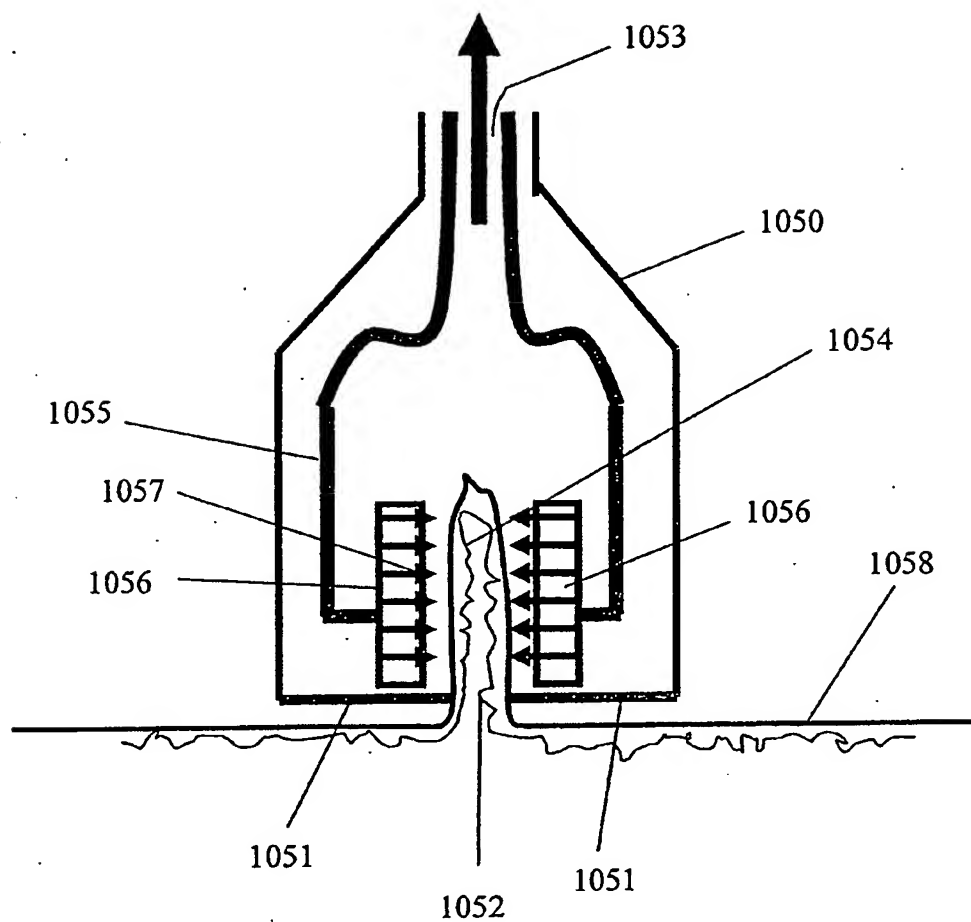
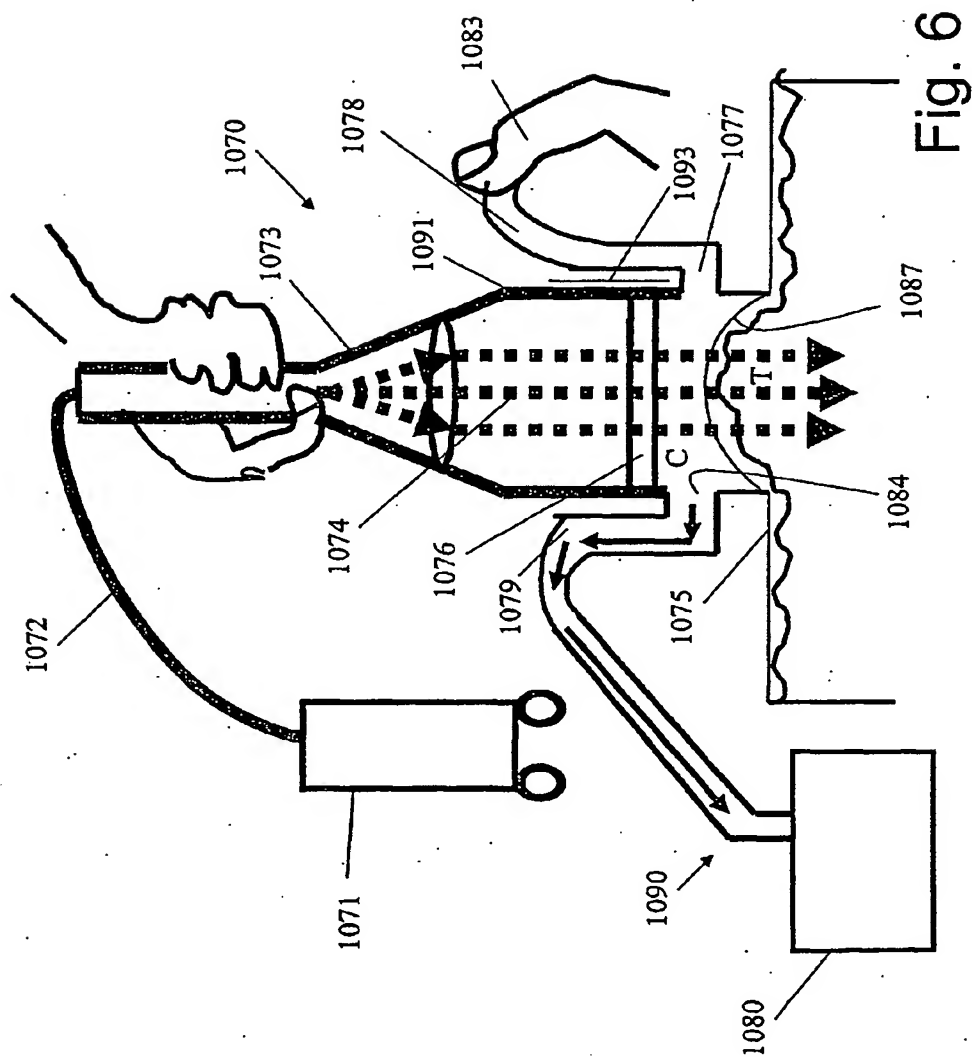


Fig. 5  
PRIOR ART



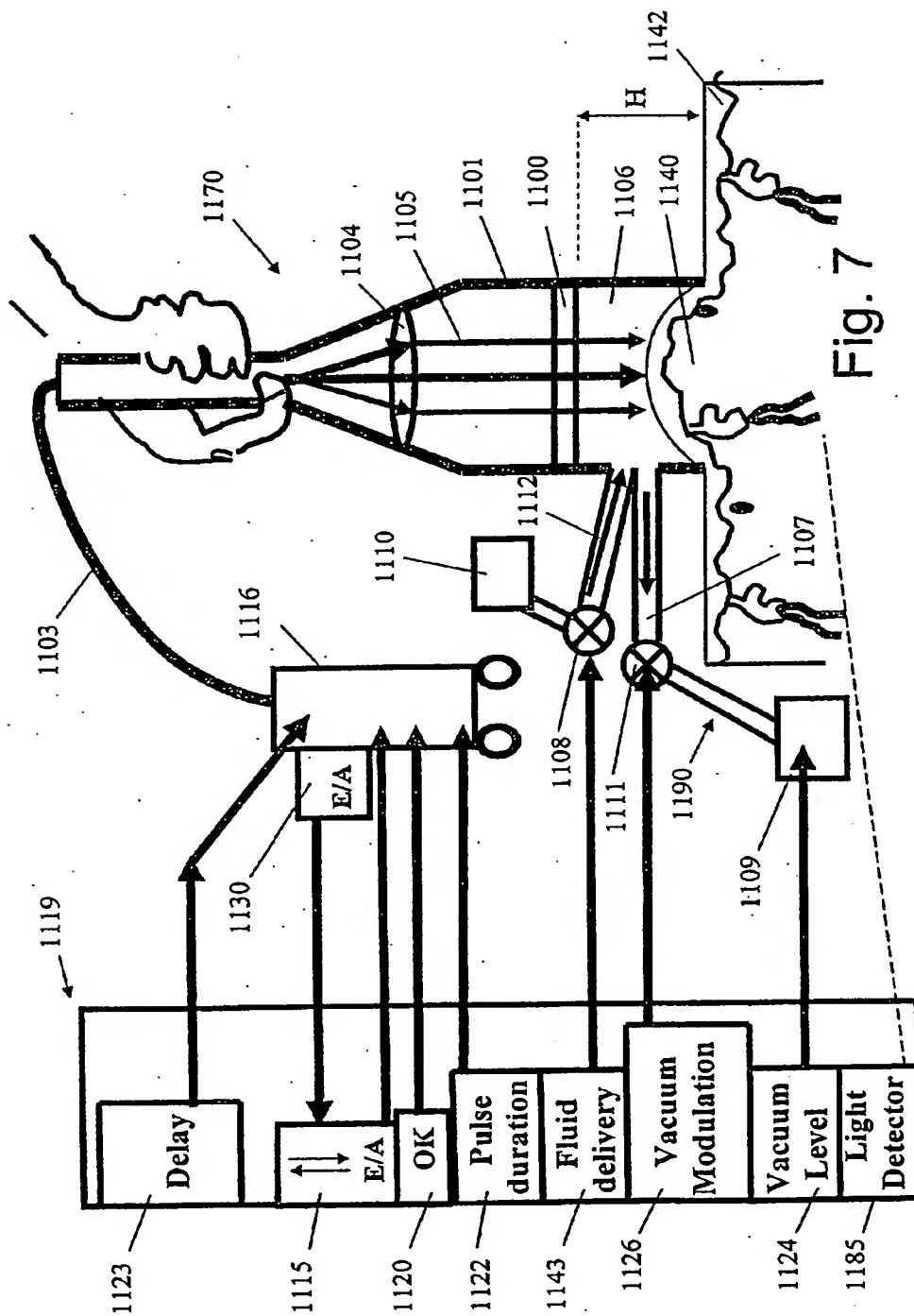


Fig. 7

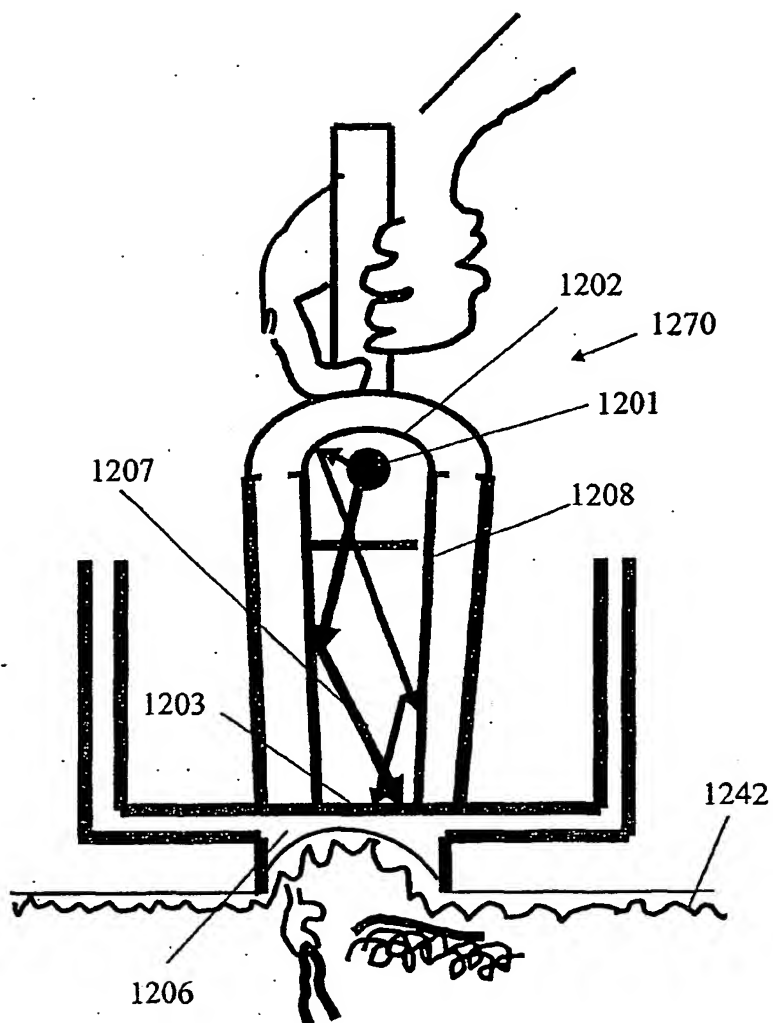


Fig. 8

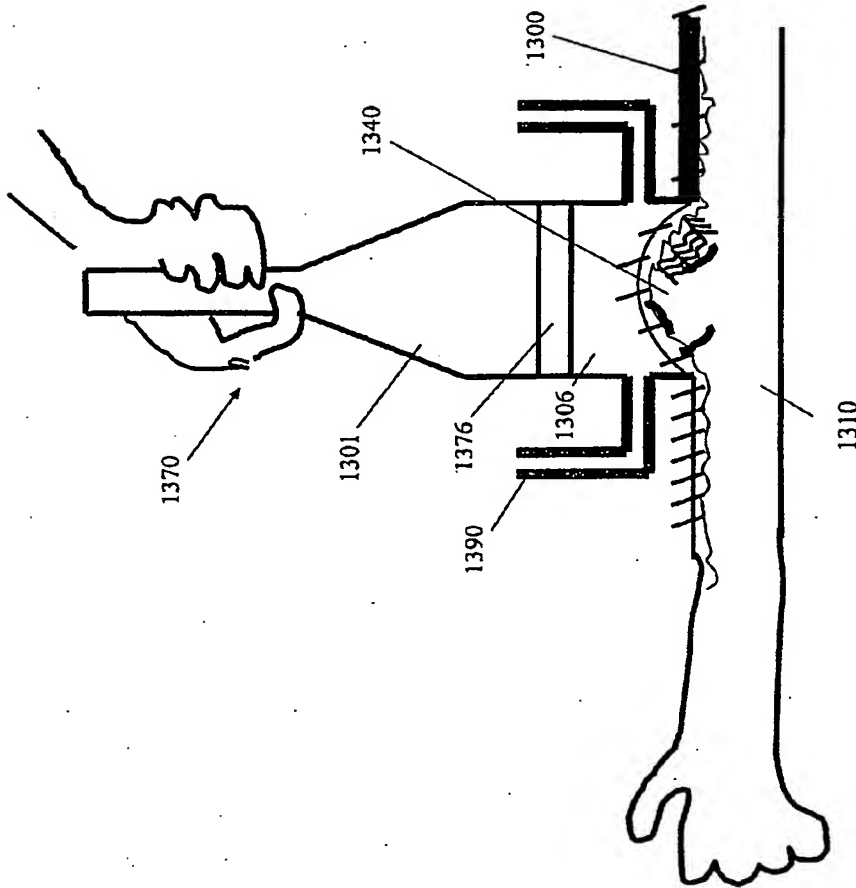
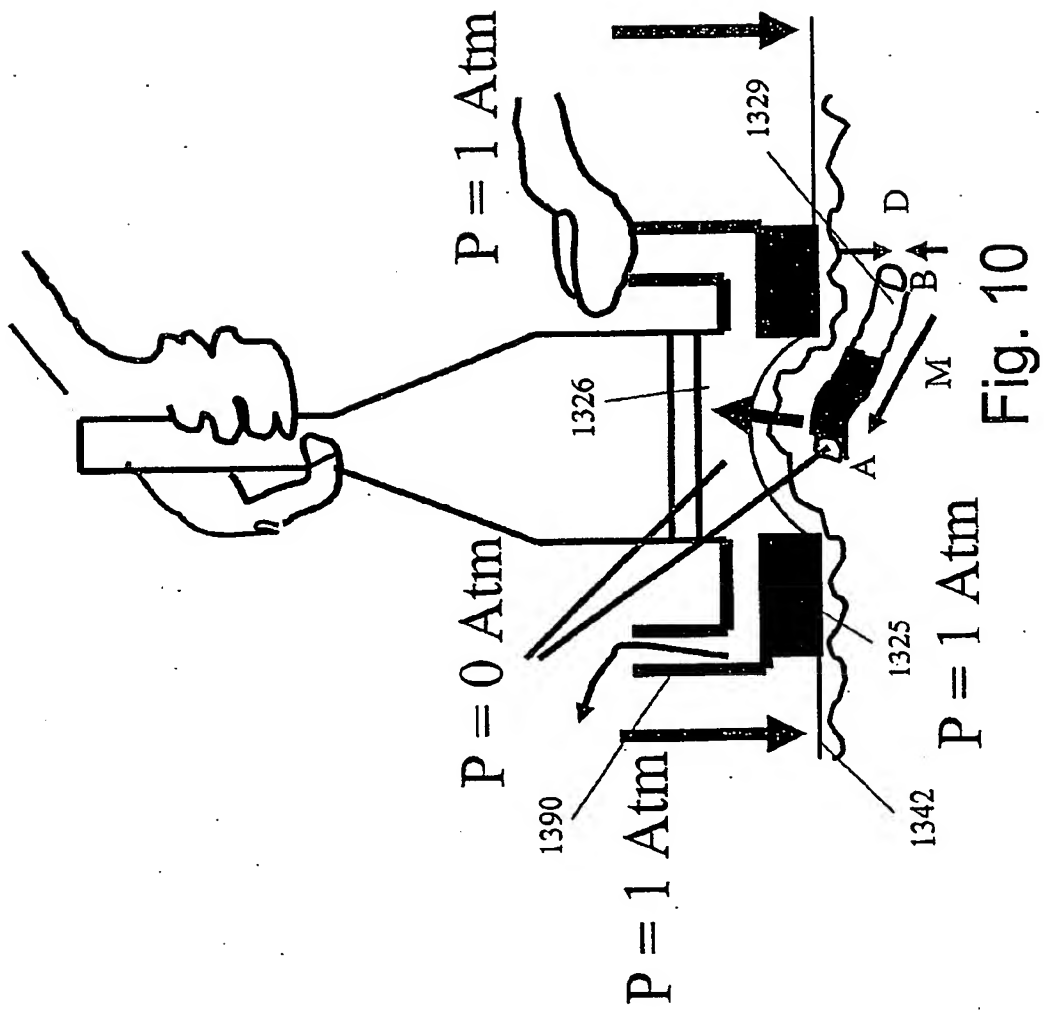


Fig. 9





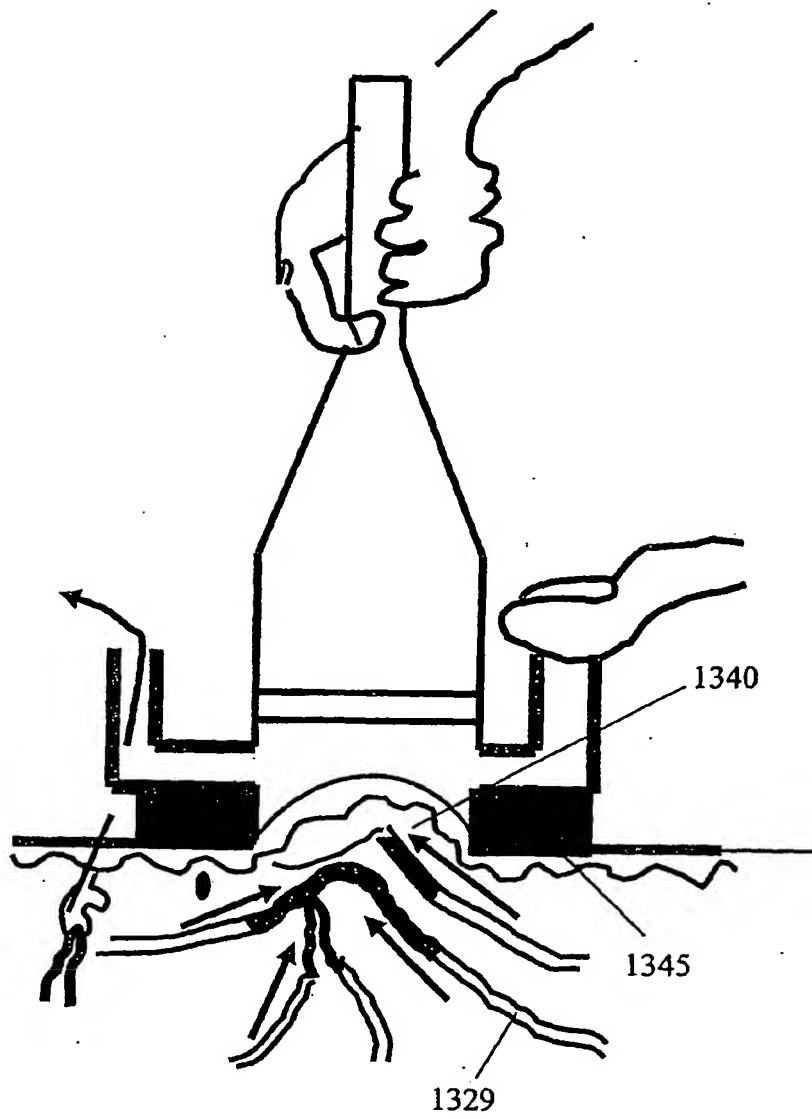


Fig. 11

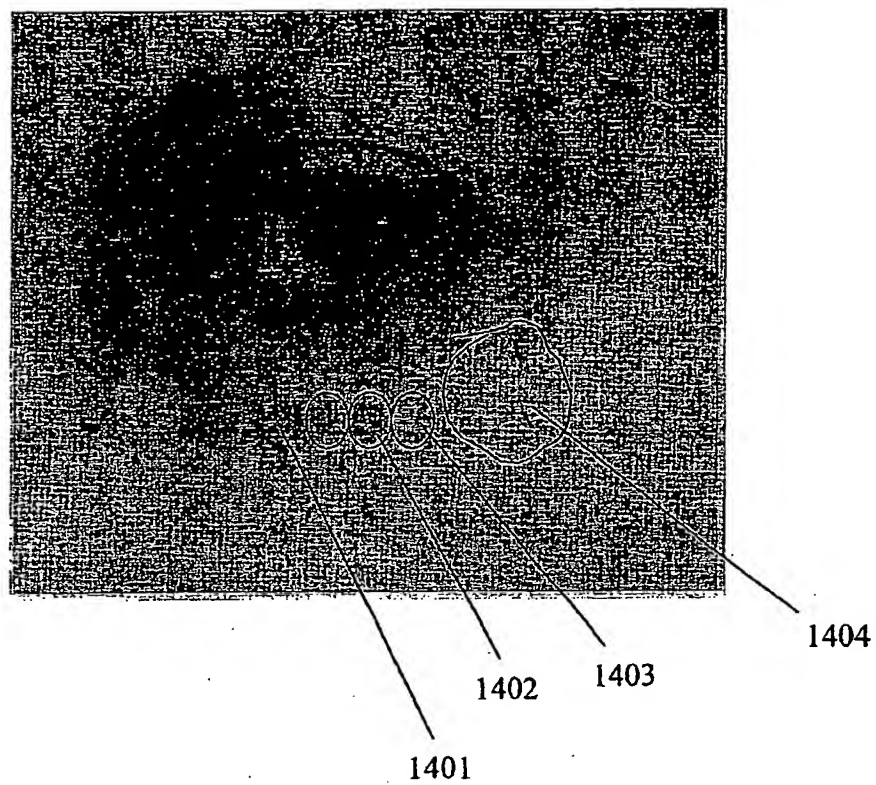


Fig. 12

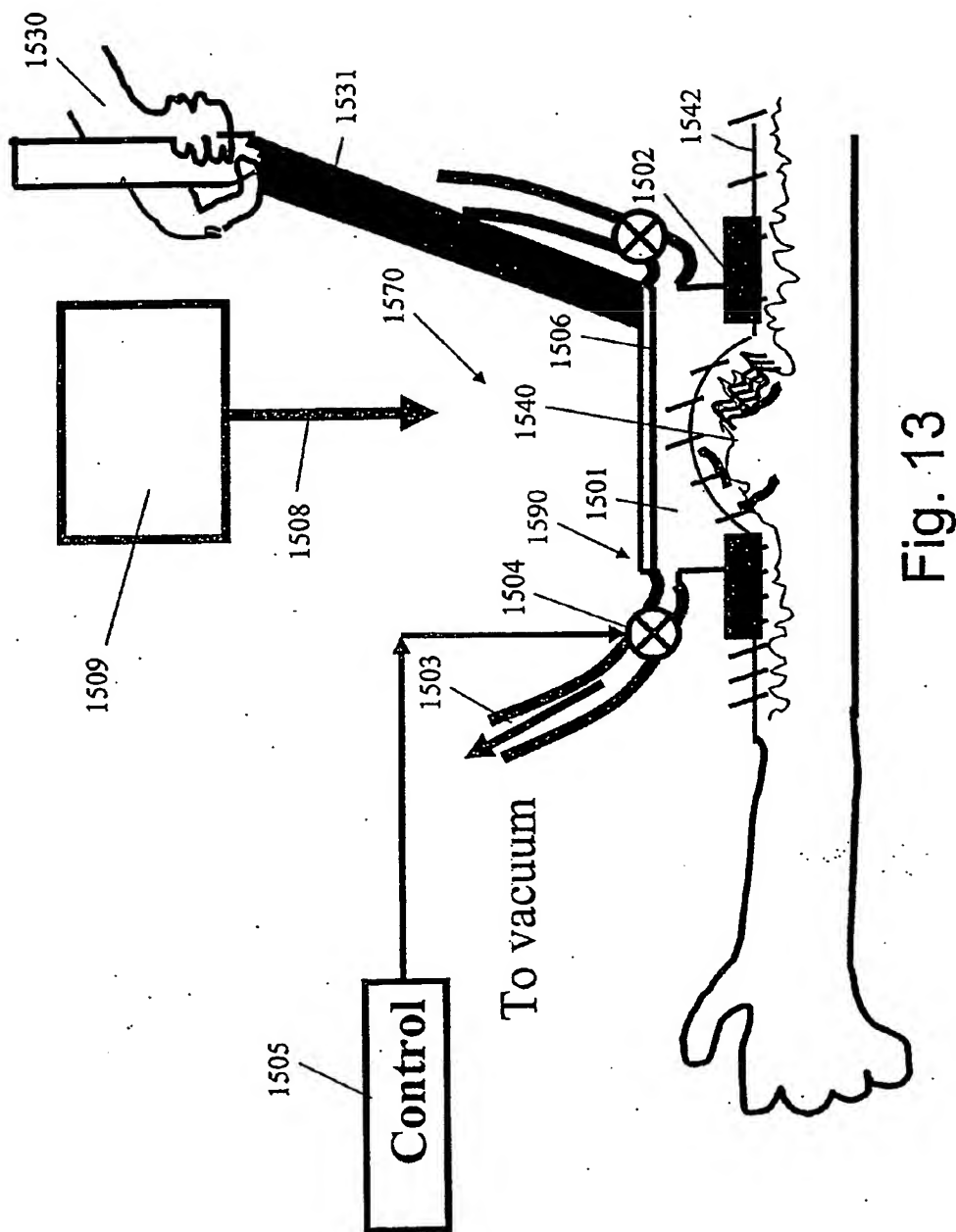
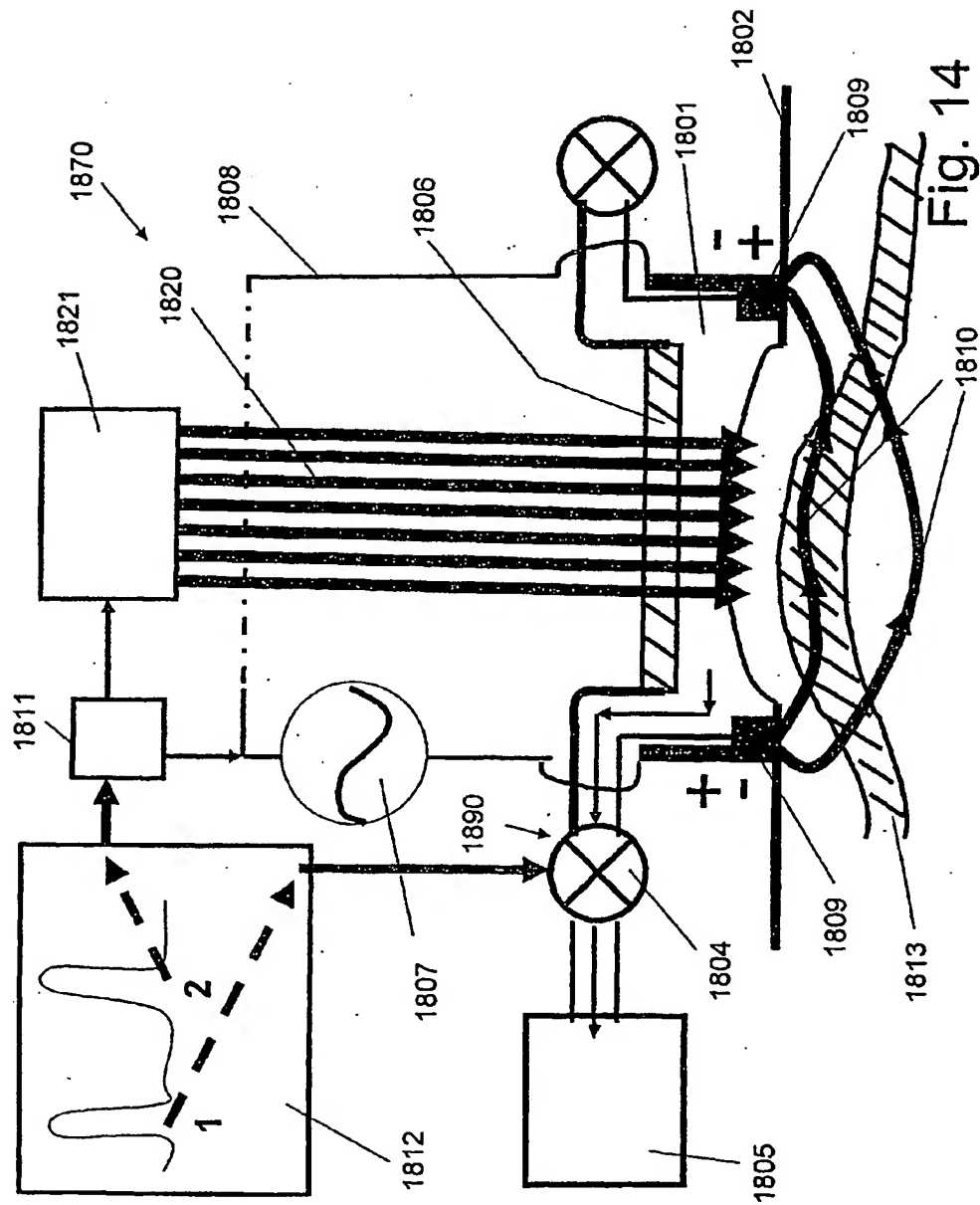
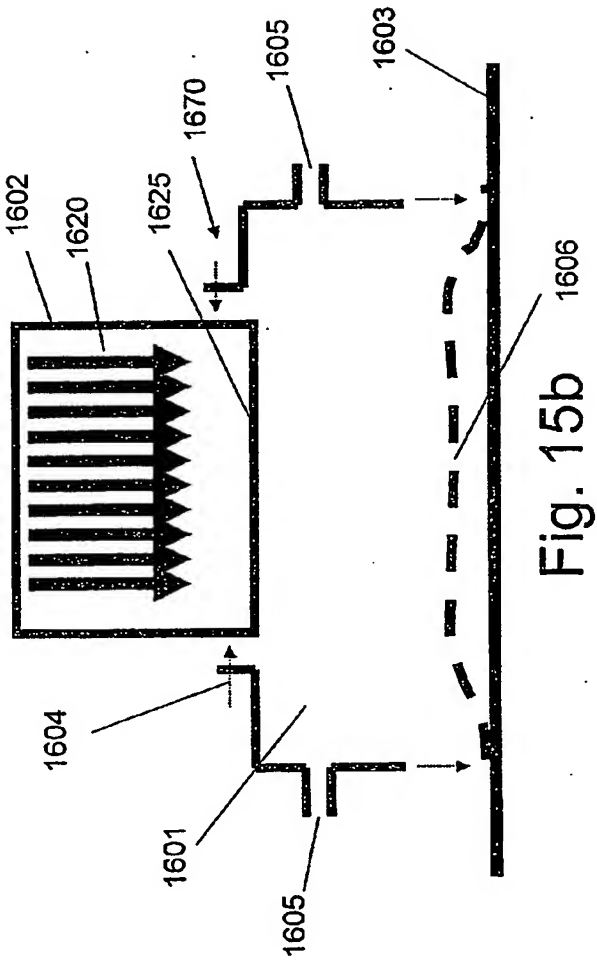
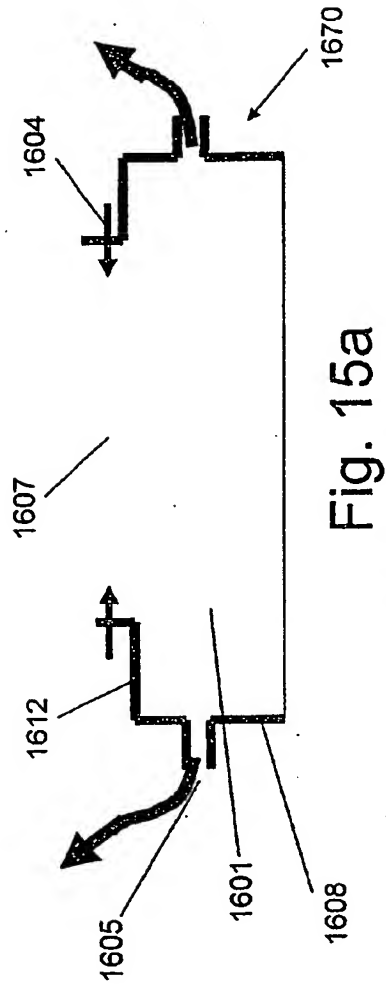


Fig. 13





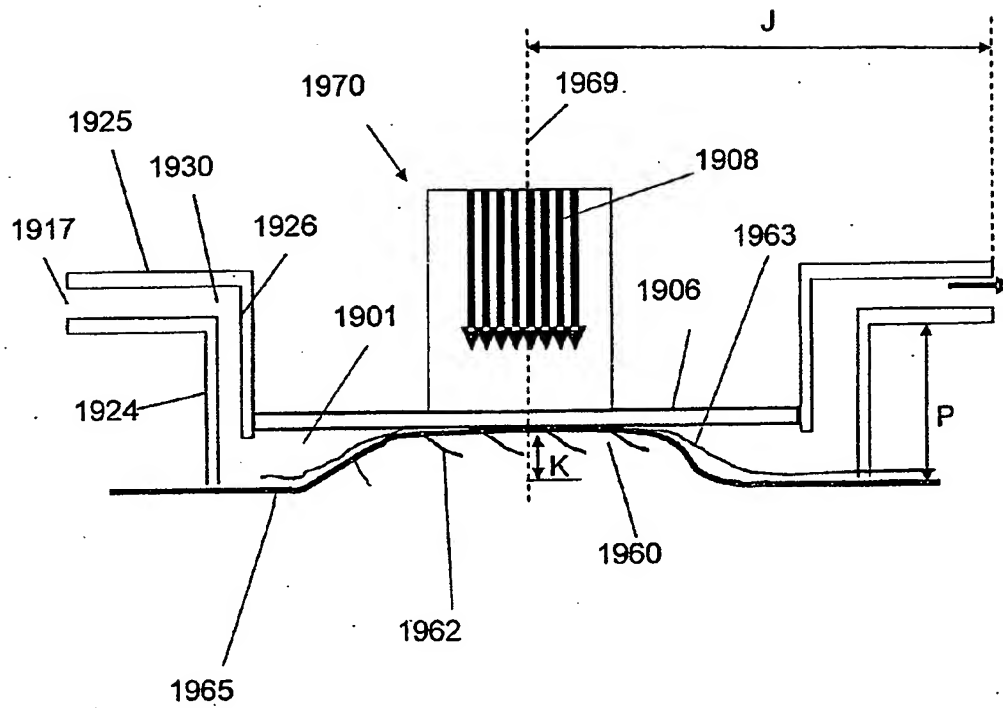


Fig. 16

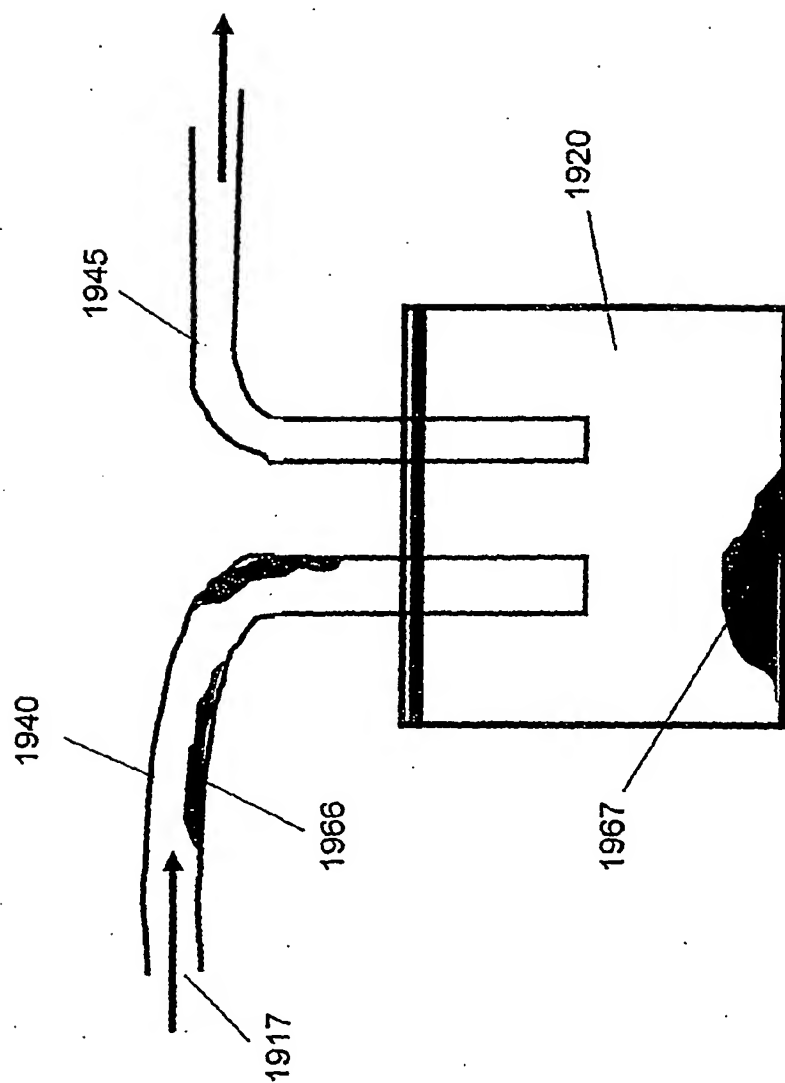


Fig. 17



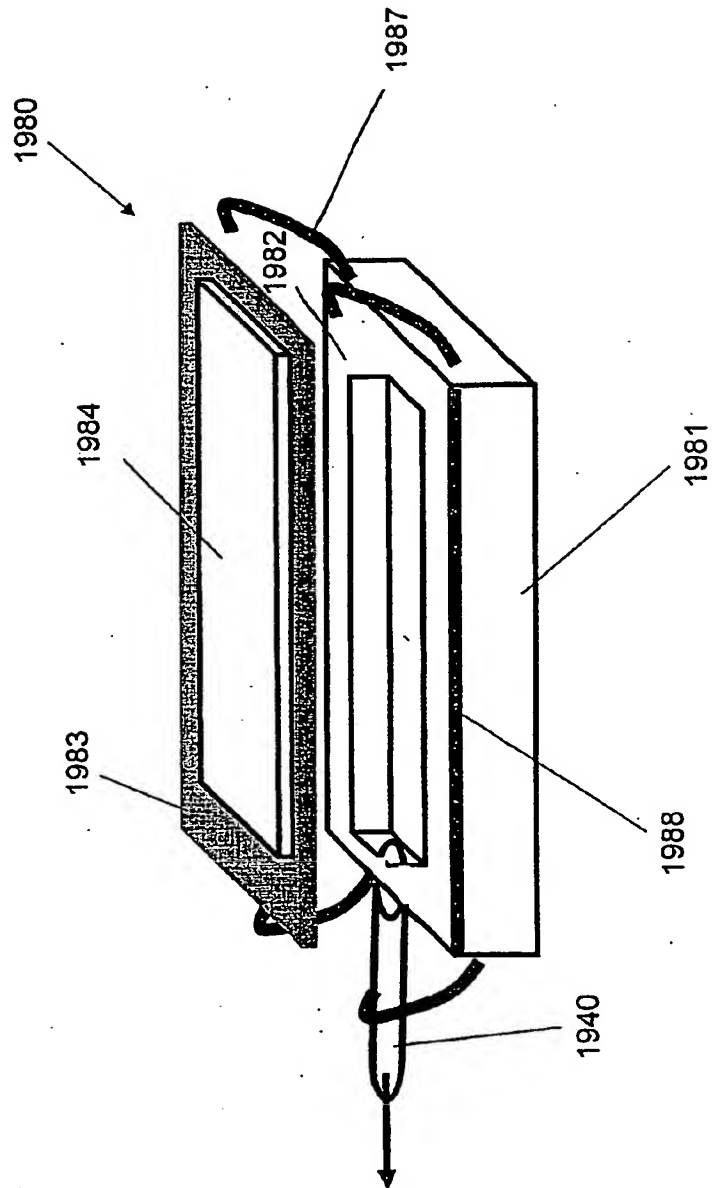


Fig. 18

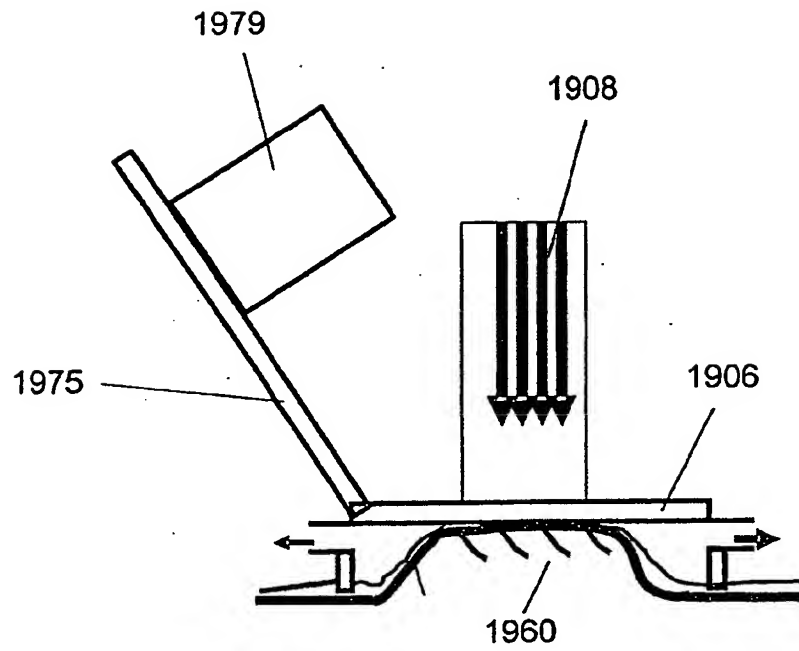


Fig. 19

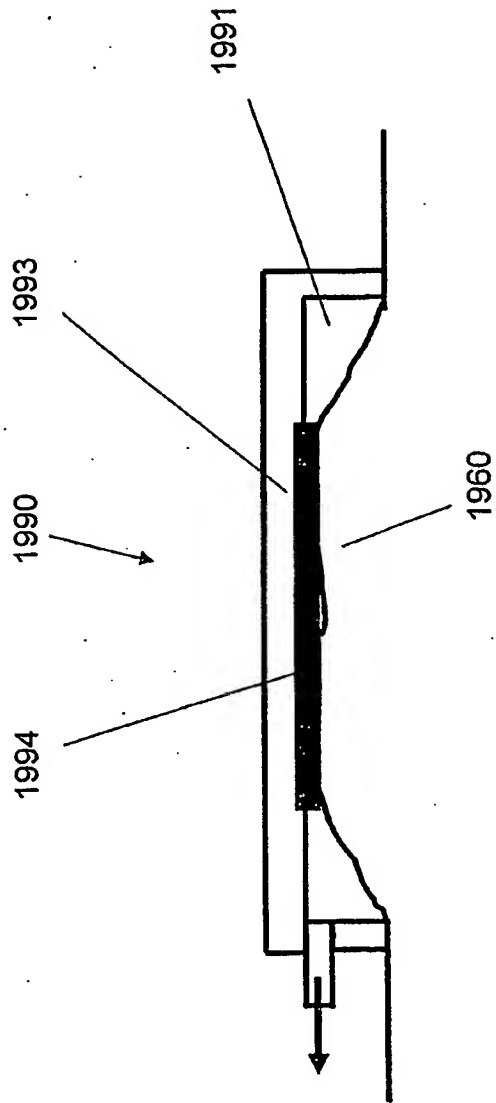


Fig. 20

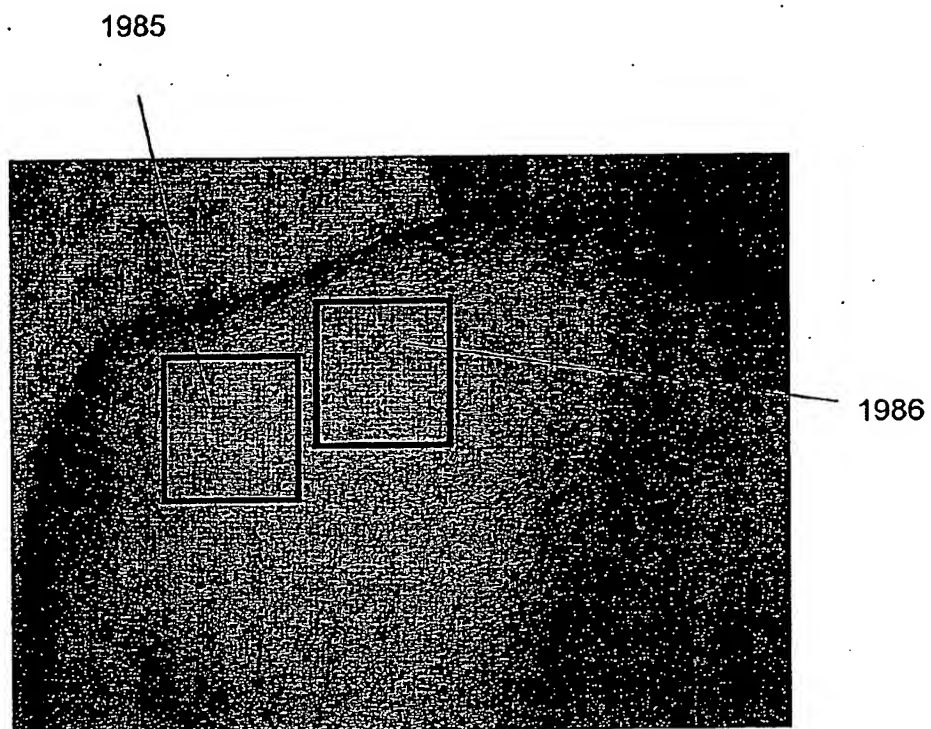


Fig. 21

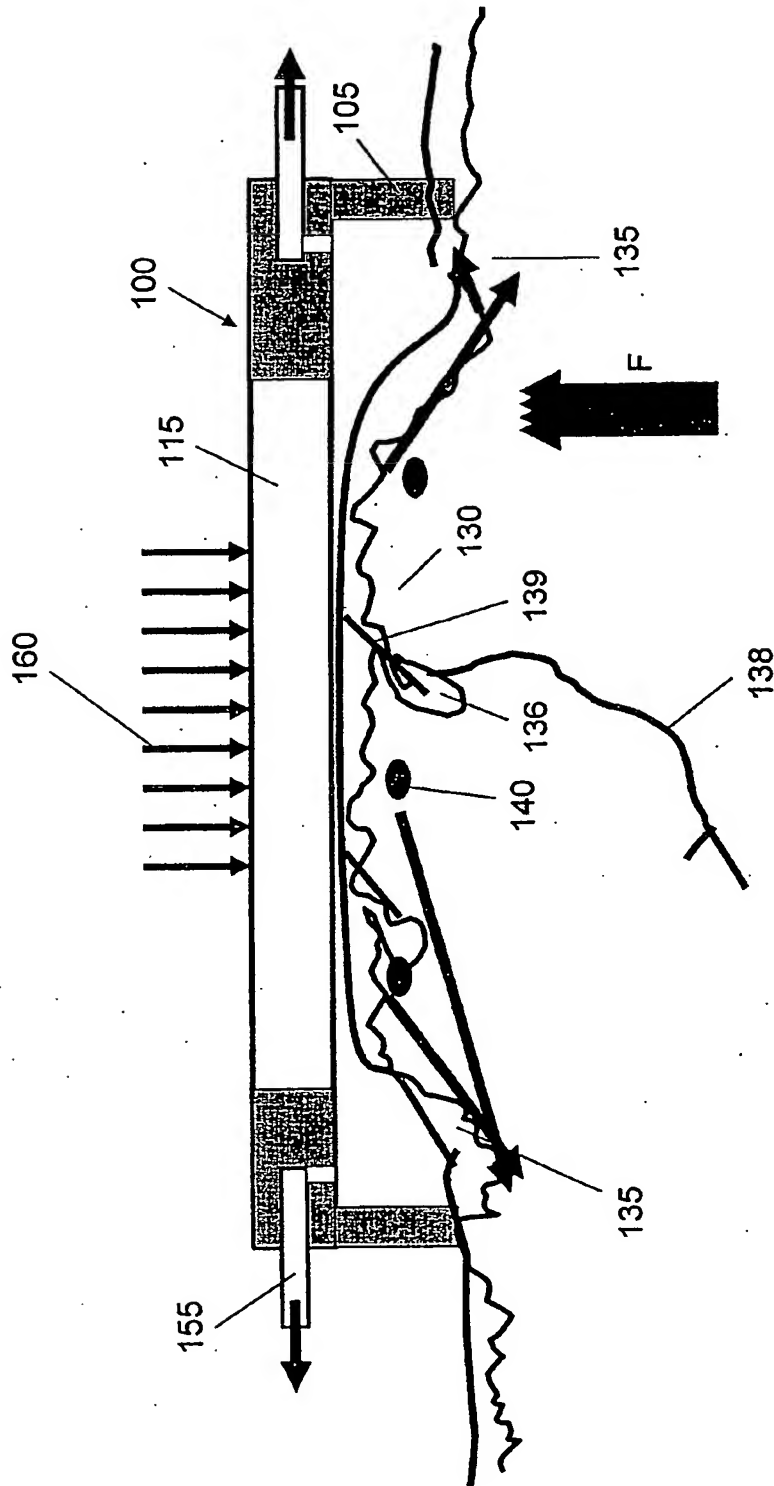


Fig. 22

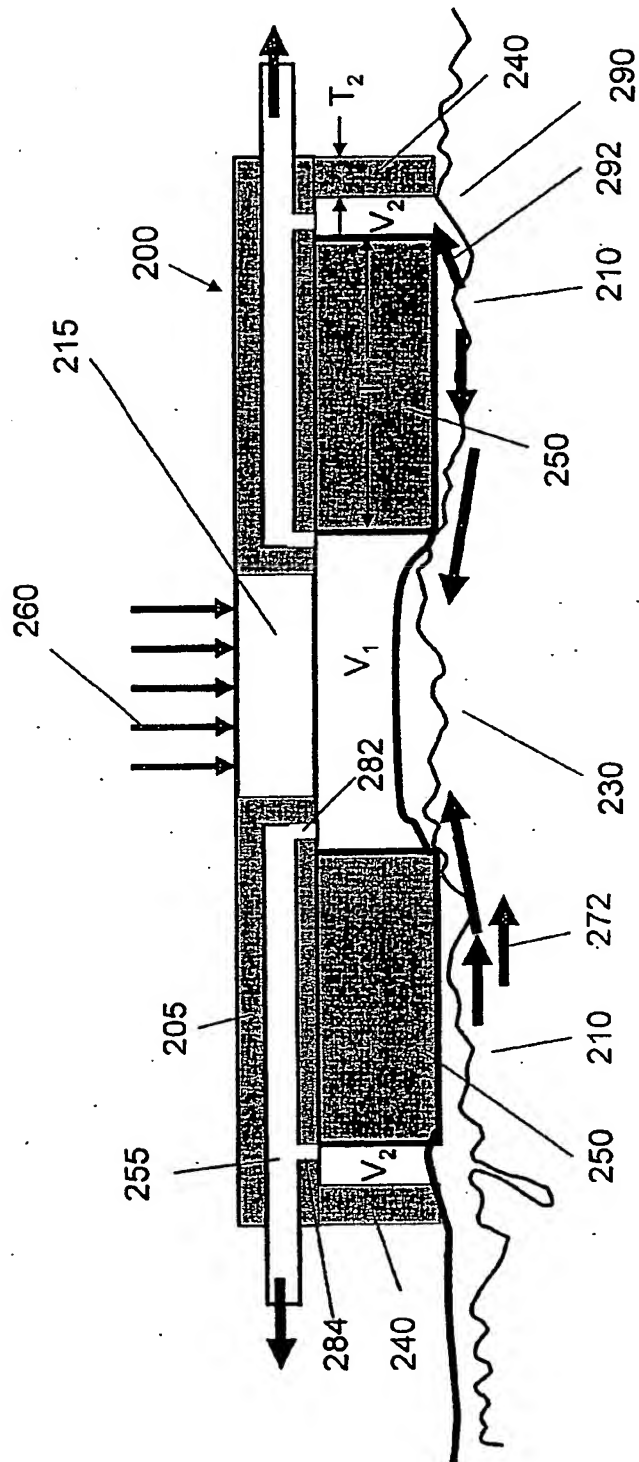


Fig. 23

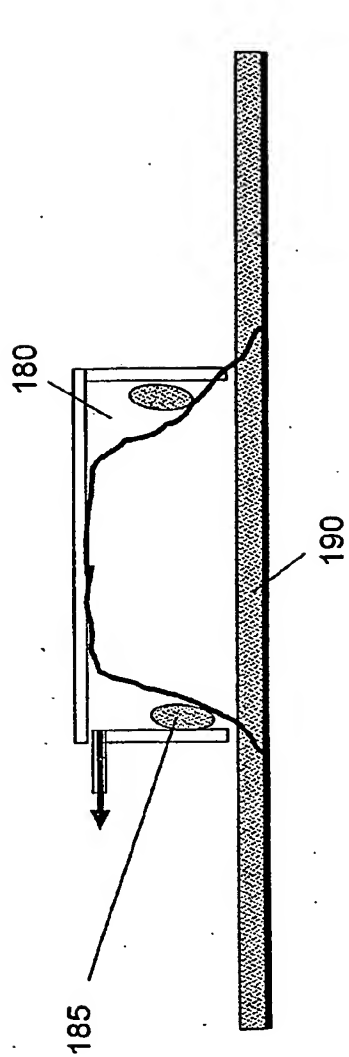


Fig. 24A

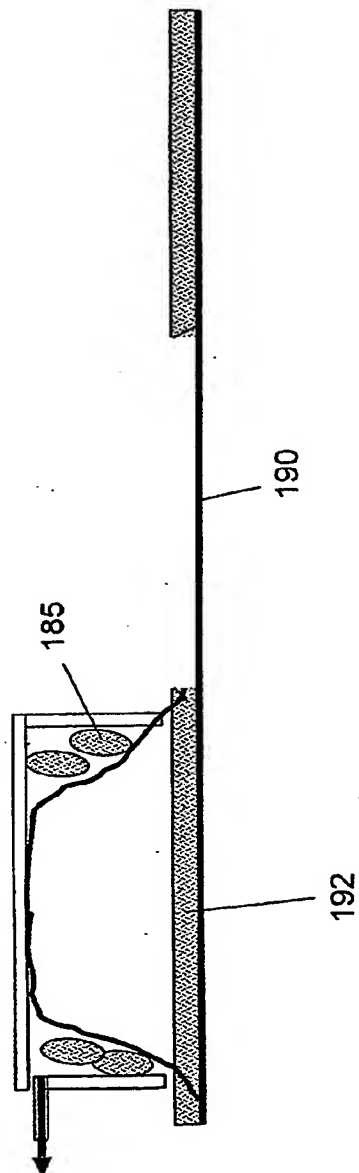


Fig. 24B

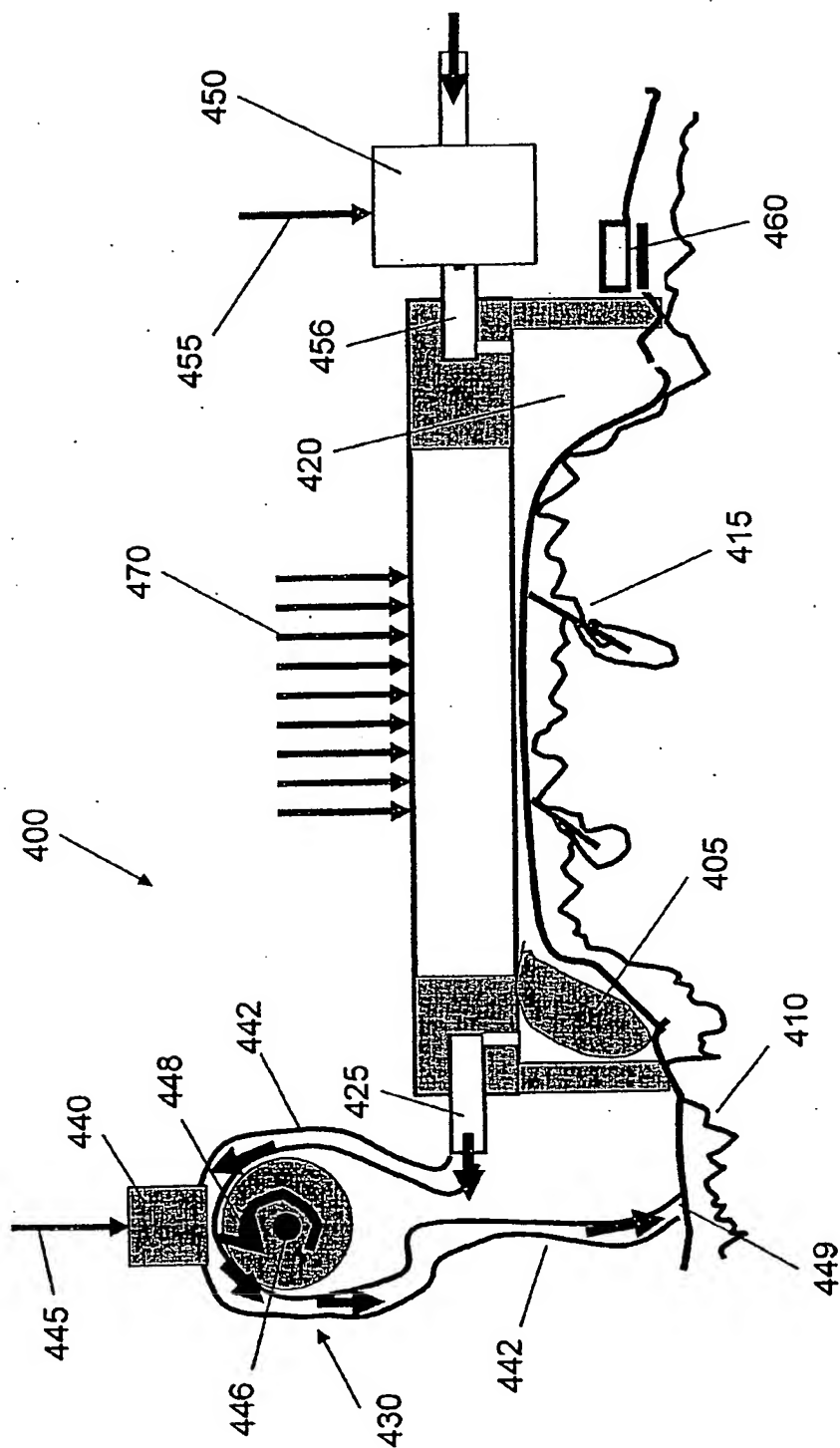
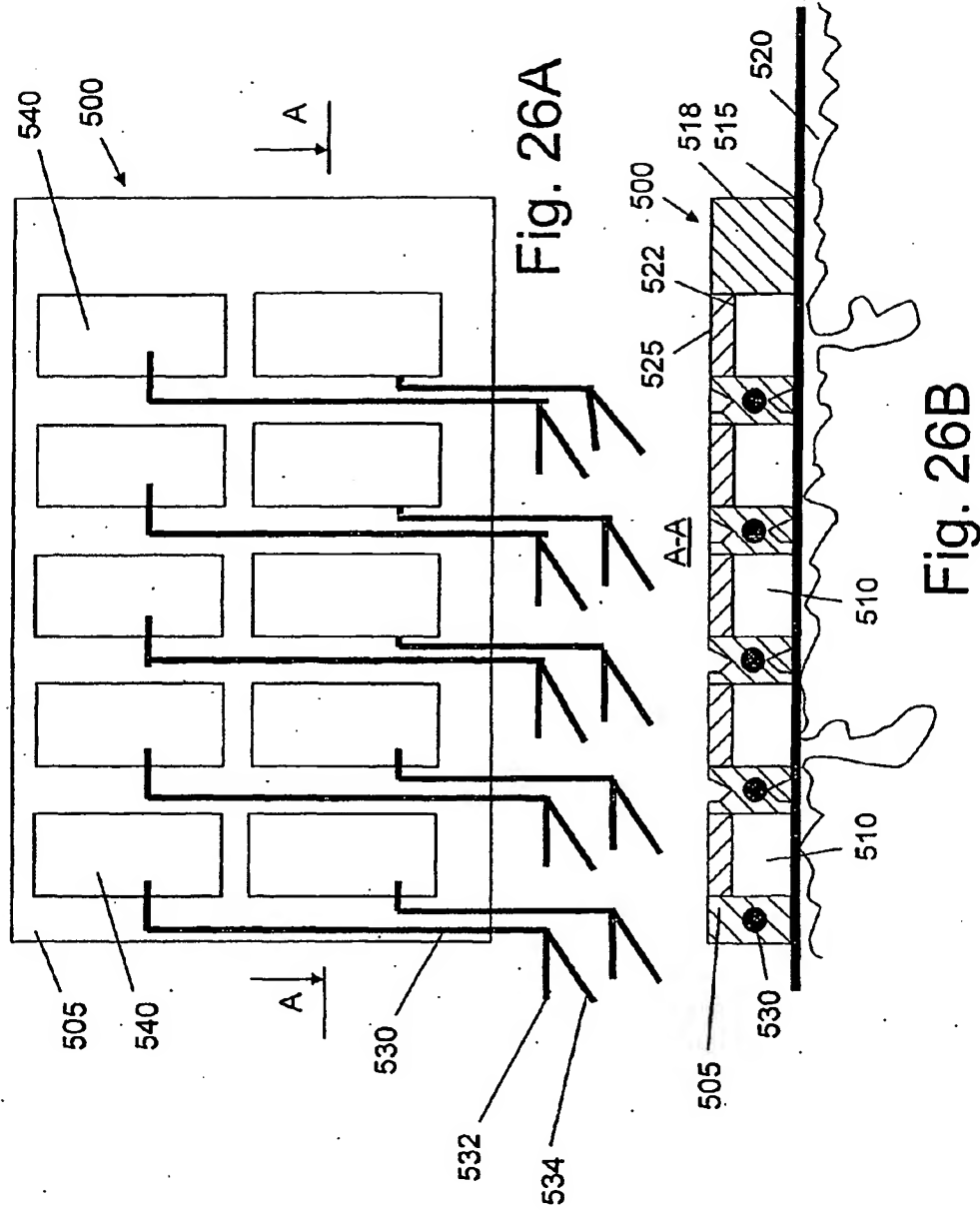
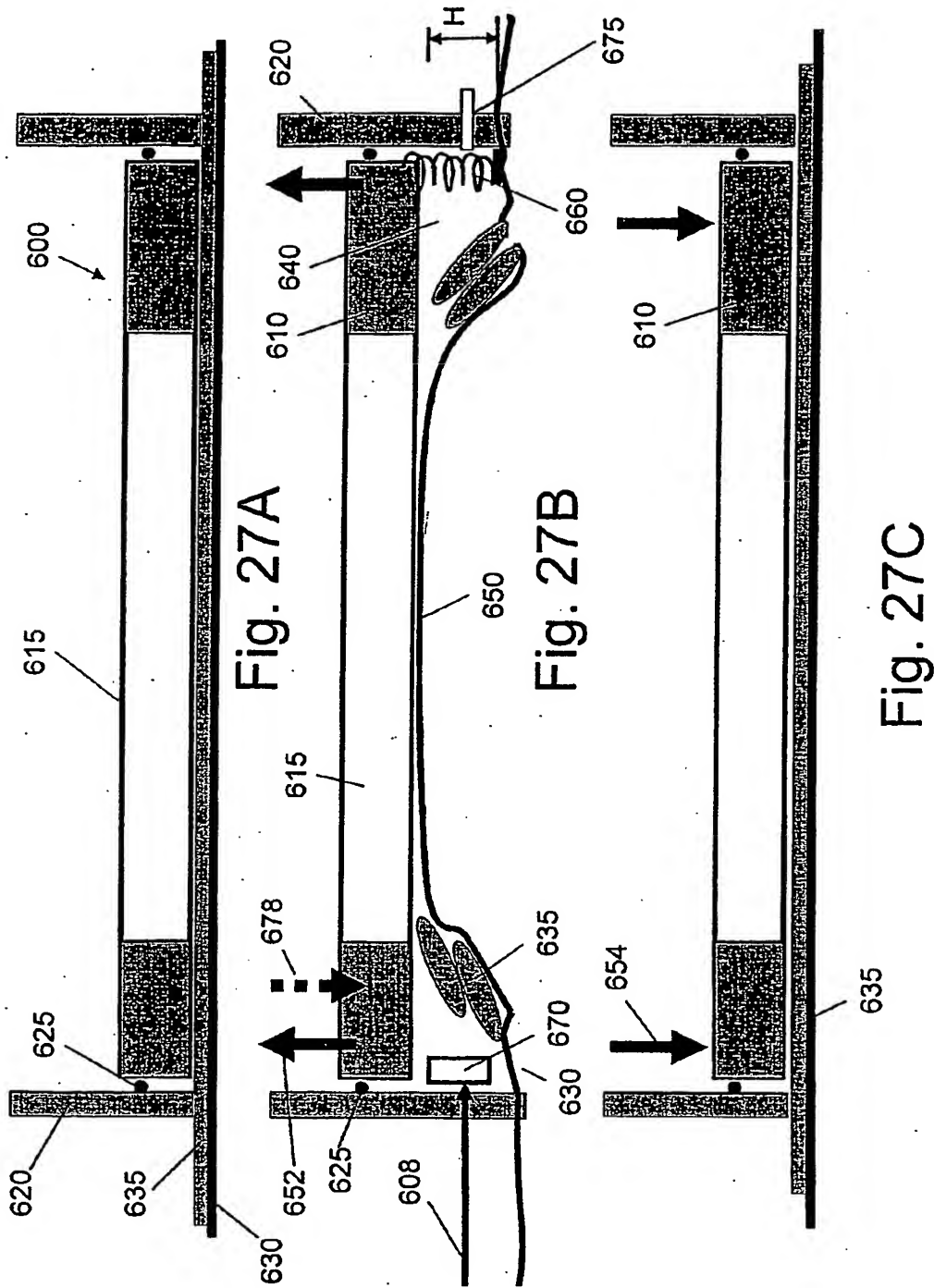
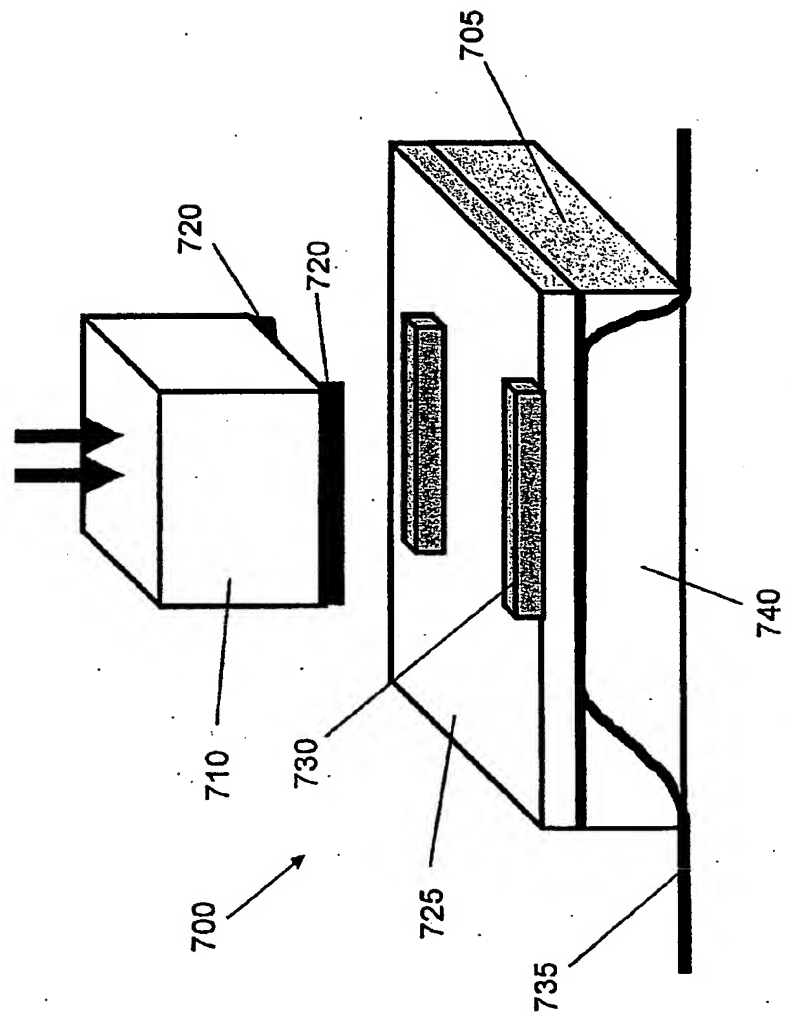


Fig. 25











European Patent  
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Application Number  
EP 05 00 7952

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			A61N A61B A61H
The present search report has been drawn up for all claims			
Place of search <b>Munich</b>		Date of completion of the search <b>15 June 2005</b>	Examiner <b>Chopinaud, M</b>
<p><b>CATEGORY OF CITED DOCUMENTS</b></p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons &amp; : member of the same patent family, corresponding document</p>			

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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(32) Priority Date: 25 October 1984 (25.10.84)

(33) Priority Country: US

(71) Applicant: CANDELA CORPORATION [US/US]; 19 Strathmore Road, Natick, MA 01760 (US).

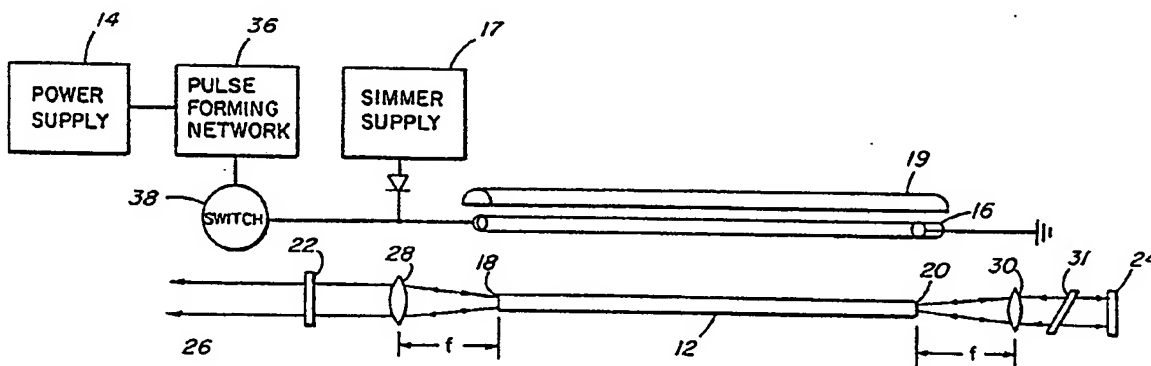
(72) Inventor: FURUMOTO, Horace ; 14 Woodridge Road, Wellesley, MA 02181 (US).

(74) Agents: SMITH, James, M. et al.; Hamilton, Brook, Smith and Reynolds, Two Militia Drive, Lexington, MA 02173 (US).

(81) Designated States: AT (European patent), AU, BE (European patent), CH (European patent), DE (European patent), DK, FI, FR (European patent), GB (European patent), IT (European patent), JP, KR, LU (European patent), NL (European patent), NO, SE (European patent).

**Published***With international search report.**Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.*

(54) Title: LONG PULSE TUNABLE DYE LASER



## (57) Abstract

A tunable dye laser has been found particularly suited to selective photothermolysis. A longer pulse duration which makes the system suitable for a wider range of applications is obtained by modifying the laser to generate a spatially noncoherent beam. The optical system at each end of the laser cell (12), which may include a lens (28, 30) or spherical mirror (32, 34), refocuses the aperture (18, 20) of the dye cell near to itself so that substantially all light emanating from the dye cell is returned to the dye cell until the light passes through one of the optic systems as a noncoherent laser beam. A tunable intracavity element (31) tunes the laser across the gain curve of the dye solution. The pulse duration of the laser beam can be selected from a range of durations up to about one millisecond.

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FR	France				



-1-

LONG PULSE TUNABLE DYE LASERDescriptionField of the Invention

05 This invention relates to lasers and in particular to laser systems suitable for medical applications such as selective photothermolysis.

Background

10 The use of lasers in selective photothermolysis has been reported by Greenwald et al., "Comparative Hystological Studies of the Tunable Dye (at 577 nm) Laser and Argon Laser: The Specific Vascular Effects of the Dye Laser", The Journal of Investigative Dermatology 77:305-310, 1981, and by Anderson and Parrish, "Selective Photothermolysis: Precise  
15 Microsurgery by Selective Absorption of Pulse Radiation", Science 220:524-527, 1983. In this technique, targeted tissues are heated by laser light, the wave length of which is selected to be specifically absorbed by the targeted tissues. The  
20 laser pulse duration is tailored to the size of the target. Tissues surrounding the targeted structures are spared.

25 The above studies highlight the need for selecting lasers which meet both the spectral requirements of a given application and pulse duration requirements. It is important that the laser be tunable to select the color of the source

-2-

to match some spectral property of the targeted tissue. The special spectral features of targets require specific wavelengths, but only require moderate linewidths (1-4 nm) to induce selective effects. Proper laser pulse duration is important to heat target tissue to denature the tissues without boiling or vaporization. The temperature limits are tight, from body temperature of 35 C to a temperature well below boiling point, about 70 C. Ordinary calorimetry states that temperature rise is proportional to energy and inversely proportional to target volume irrespective of the time it takes to deliver the energy. If thermal diffusivity is added there is a pulse duration criterion and the energy must be deposited quickly to minimize heat dissipation to surrounding tissue. However, selective photothermolysis heat must not be deposited too quickly so as to exceed the boiling point in the targeted zone.

The situation gets more complex if small absorbing chromophores such as hemoglobin in blood cells are used as absorbers to treat blood vessels which are an order of magnitude larger. The radiation must be added at low intensities so as not to vaporize the small cells, left on long enough to heat the blood vessels by thermal diffusion to the point of denaturation and then turned off before the surrounding tissue is damaged.

Some control in intensity is available by the adjustment of the spot size of the pulsed radiation

-3-

source. A source capable of delivering more than a joule is necessary so that spot sizes do not become too tiny with a concomittant increase in treatment time.

05       The above studies have shown the dye laser to be particularly suited to selective photother-  
molysis. Dye lasers are readily tunable to selected  
wave lengths by means of the choice of dye, wave-  
length selective filters in the cavity and the like.  
10       Further, dye lasers can provide high output energies and short pulse durations. Unfortunately, the  
typical dye laser pulse duration of only a few  
microseconds or less is too short for many applica-  
tions using selective photothermolysis. Dye lasers  
15       with nanosecond or shorter pulses are preferred for subcellular organelle targeting and microsecond or  
shorter pulses are preferred for cell targeting.  
However, dye lasers do not typically provide the  
millisecond pulses which are best for blood vessels  
20       and other small structures.

It is generally recognized that the quenching  
of a dye laser after microseconds may be due to the  
accumulation of dye molecules in the triplet state  
by means of intersystem crossing from the singlet  
25       state. Laser action in a dye laser starts from the  
singlet states. Molecules which cross over to the  
triplet state often absorb at the laser wavelength  
and inhibit laser action. The triplet state effect  
has been investigated and triplet state quenchers  
30       have been reported for specific dyes. However,

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triplet quenchers for all dyes used in lasers have not been identified. But, even with the use of triplet quenchers, pulse durations of several hundred microseconds have only been obtained at low energy outputs of not more than a few tenths of a joule.

A second problem that makes it difficult to generate long pulses in a dye laser is the distortion of the liquid amplifying medium by absorbed, conducted and convected heat from the laser excitation source. Such distortions are unavoidable but must be minimized for laser action to continue for milliseconds.

#### Disclosure of the Invention

A laser has been developed which is more suitable for selective photothermolysis because the laser pulse duration is adjustable to durations approaching one millisecond. The present laser is based on the recognition that thermal distortion in the laser medium results in changes in the index of refraction in the medium and loss of resonating modes for which the laser is designed.

In accordance with principles of the invention, a multiple pass light amplifier, which may be considered a spatially noncoherent laser, comprises a cell having a medium excitable to an energy level with net optical gain and having apertures at opposite ends of the cell. The Fresnel number of the cell is greater than one, distinguishing it from

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05 wave guide lasers. Means such as a flashlamp is  
provided for raising the medium to an inverted  
energy configuration. An optical system at each end  
of the cell images each aperture upon itself. As a  
result, substantially all light emanating from the  
aperture, within a wavelength band determined by the  
dye solution and any tuning element, is returned to  
the cell through the aperture. The optical system  
at one end of the cell allows part of the light to  
10 escape and be used.

The resultant beam of light which passes  
through one of the optical systems has directional  
concentration to a solid angle substantially less  
than one steradian, in the order of  $10^{-4}$  steradian,  
15 although that concentration is somewhat less than  
the solid angle of  $10^{-8}$  steradian of conventional  
lasers. A pulse length greater than 100 micro-  
seconds, even approaching one millisecond, is  
possible even with output powers of over one tenth  
20 joule. In fact, a pulse duration of 500 micro-  
seconds has been obtained with output powers in the  
order of joules.

In one form of the embodiment, the means for  
imaging the aperture on itself is a spherical mirror  
25 located a distance from the aperture about equal to  
its radius of curvature. In another embodiment, a  
lens is positioned between the aperture and the flat  
mirror. The lens is positioned at about its focal  
length from the aperture. The light emanating from  
30 the cell is collected by the optical system and

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reflected back into the cell. The light traverses the cell in a number of total internal reflections off other cell walls. The dye solution in an excited state amplifies the light rays traversing the cell. The gain medium has a continually changing index of refraction, light rays traversing the cell have no fixed pattern and resonator modes are not established; rather, the spontaneous emission localized in a cone determined by the reimaging optics is amplified on successive round trips through the cell throughout the duration of the laser pulse.

In a system designed specifically for selective photothermolysis, the power supplied to the flashlamp is provided with a variable pulse length circuit which provides for variable length pulses in the range of at least about 10 to 500 microseconds. Preferably, the system allows for pulses of up to one millisecond duration. An output of at least about one joule is provided.

#### Description of the Drawings

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily

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to scale, emphasis instead being placed on illustrating the principles of the invention.

Fig. 1 is an illustration of a preferred embodiment of the invention.

05 Fig. 2 is an illustration of an alternative embodiment of the invention using spherical mirrors.

Fig. 3 graphically illustrates a typical laser pulse plotted over the flashlamp excitation pulse and showing thermal distortion in the laser pulse.

10 Fig. 4 is a graphical illustration of a laser pulse over the flashlamp excitation pulse in a system embodying the present invention.

Fig. 5 is yet another embodiment of the invention having a bent gain medium.

15 Description of Preferred Embodiments

The earliest work in generating long pulses with dye laser concentrated on reducing triplet absorption effects. Dissolved oxygen and other chemicals considered to be triplet quenchers were  
20 added to the dye solution to deactivate any triplet states generated by long excitation pulses. Our present studies show that the additives or triplet quenchers do help to increase pulse duration. However, the additives may also help increase pulse  
25 duration because they lower laser threshold levels rather than minimize triplet absorption.

The early termination of laser action during a long excitation pulse is considered to be primarily of thermal origin. Heat is absorbed by

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the solution and heat is convected from the lamp to the dye cell if the pulse is long enough. Acoustic velocities are in the order of 0.5 mm/microsecond, and with a dye cell bore of 4 or 5 mm there will be density and index of refraction gradients throughout the cell when laser pulses are longer than ten microseconds. If the gradients are very large, the result is a loss of identifiable resonating modes and quenching of the laser output.

A laser system embodying the present invention is shown in Fig. 1. The system is a modification of a conventional flashlamp excited dye laser. In such lasers, a laser medium in the form of a dye carried by a liquid is directed through the dye cell from one end to the other. Through external temperature control equipment, the medium is maintained at a uniform and constant temperature. To excite the laser medium, a high voltage developed in a power supply 14 is applied across a flashlamp 16. As in conventional flashlamp excited dye lasers, a small simmering current may be applied from a supply 17 to the flashlamp prior to starting a pulse from the supply 14 in order to develop a significant level of ionization in the flashlamp prior to discharge.

Light energy from the flashlamp is directed inward to the laser medium by means of a reflector 19. The energy from the flashlamp is absorbed by the laser medium and moves molecules in the medium from the ground state to excited singlet states. As in conventional lasers, as those molecules return to



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their ground state they emit photons of a particular wavelength. Part of the light emanates from apertures 18 and 20 at each end of the dye cell. The light is returned through the apertures into the cell by respective mirrors 22 and 24. The returned photons react with molecules of the laser medium in the excited singlet state to cause those molecules to return to the ground state and themselves emit photons of the particular frequency. The thus emitted photons are in phase with the photons striking the molecules and are directed in the same direction as the original photons.

In a conventional laser, the optics at each end of the dye cell 12 are designed such that the photons travelling back and forth between the two mirrors 22 and 24 follow specific paths such that the photons resonate in particular modes. The photons resonate at a common frequency and phase. Finally, the light between the mirrors reaches an intensity such that a measurable amount passes through the mirror 22, which is not a full reflector, as a beam 26. In a conventional laser, the beam 26 is coherent and the divergence of that beam is very small, in the order of  $10^{-8}$  steradians. To provide the resonating modes of a conventional laser, the laser optics must be precisely designed. Thermal distortions in the laser medium result in gradients in the index of refraction of the medium

-10-

which in turn destroy the precise optic specifications of the system. The result is a loss of resonating modes and quenching of the laser output.

05 In the system of Fig. 1, lenses 28 and 30 are provided between respective apertures 18, 20 and mirrors 22, 24. In accordance with the present invention, the optics at each end of the dye cell are designed to return substantially all of the  
10 light emanating from the apertures 18 and 20 back into the dye cell rather than to return just the spatially coherent light which travels substantially coaxially in the system. There is no attempt to establish resonating and coherent modes in the present system.

15 The lenses 28 and 30 are positioned at about their focal lengths  $f$  from the apertures 18 and 20. As a result, each aperture is reimaged onto itself through the lenses and flat mirrors. By thus selecting and positioning the lenses, substantially  
20 all of the light emanating from the apertures, independent of resonating modes, is returned to the dye cell.

25 The optics mix the resonating rays and thoroughly homogenize the beams. Any thermal distortions which are induced by the flashlamp are of little consequence because there are no resonator modes. The rays traverse the cell and are amplified but do not follow a precise path determined by the optics. Those rays that are highly deviated as to  
30 miss the dye cell are lost. The homogenization is

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random and there is no phase relation at the wave front. The modes if any are randomly oriented and completely homogenized. The randomness is spatial as well as temporal. Spatial coherence is not  
05 preserved but monochromaticity can be partially preserved with suitable wavelength selective elements. The medium has gain and a definite threshold and therefore is classified a laser.

As in conventional lasers, a tuning element 31  
10 may be provided to tune the laser output within the gain curve of the dye solution. The tuning element can reduce the bandwidth of the beam to less than .01 nanometers and is used to match the absorption band of the target to enhance the desired physio-  
15 logical effects. The most effective tuning elements are those that do not depend on this spatial coherence. The tuning element may be an etalon, a birefringent filter or a prism.

Fig. 2 illustrates an alternative embodiment of  
20 the invention in which the optics at each end of the dye cell are replaced with spherical mirrors 32 and 34. Each mirror is positioned at a distance from the aperture 18, 20 which about equals its radius of curvature R. Each spherical mirror reimages the  
25 aperture back on itself as do the optical systems in the prior embodiment.

The systems of Figs. 1 and 2 do not provide the coherent radiation of a conventional laser, and  
30 their output beams diverge across a solid angle of  $10^{-4}$  steradians. However, in an application such as

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selective photothermolysis, the large depth of field obtained from coherent radiation is not required. The concentration of light, though not as great as with the conventional laser, is significantly greater than the one steradian obtainable with nonlaser radiation and is adequate for selective photothermolysis. The advantage of the present system, as applied to selective photothermolysis, is that the beam is not limited by thermal distortion to a pulse duration of less than ten microseconds. Rather, pulse durations approaching one millisecond are possible.

There is a relation between laser pulse duration and the aspect ratio  $l/d$  where  $l$  is the cell length and  $d$  is the bore. A 12" gain length with a 4 mm bore cell lases for 125 microseconds before beam break up occurs. An 18" gain length laser with a 4 mm bore using the same set of optics lases for over 400 microseconds. The larger aspect ratio  $a/l$  where  $a$  is the radius of the dye cell bore and  $l$  the length of the cell, the longer are the pulses. The pumping intensities are kept constant by controlling the current density through the flashlamp. Energy levels up to five joules have been measured.

With the longer pulse durations available with the present system, the dye cell is now suited to a wider range of applications. Further, the pulse duration can be made variable to meet a number of different applications. To that end, a pulse forming network 36 is provided to generate electrical

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pulses and transmit the pulses to the flashlamp 16, through a relay switch 38. The pulse width may be selected from the range of 10 microseconds to 500 microseconds and preferably to as high as one millisecond.

Standard plane-plane or confocal laser resonators show thermal effects at times in the order of ten microseconds. The symptom for thermal distortion is an instability in the amplitude of the laser output pulse. In general, flashlamp excitation pulses have a smooth envelope and the laser output pulse closely follows the excitation pulse. If thermal effects distort the laser medium, then the laser intensity will show an amplitude fluctuation. Figure 3 shows the output of a laser with a standard laser configuration; the laser pulse shows amplitude fluctuations after ten microseconds. Such amplitude fluctuations are seen in all long pulse dye lasers that use standard laser resonators. Figure 4 shows the same laser with a laser resonator configuration according to this invention that compensates for the thermal effects; the amplitude fluctuations are eliminated.

This system is similar to a waveguide resonator in that the sum of the focal lengths is less than 1, the optical length between the mirrors. However, it is not a waveguide resonator for the following reasons. (1) There is no restriction on the Fresnel number of the guide. The Fresnel number is equal to  $a^2/\lambda$  where  $a$  is the radius of the dye cell,  $\lambda$  is the

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wavelength, and  $l$  is the length of the cell. The waveguide resonator works with guides that have a Fresnel number less than one. Typical Fresnel number for the long pulse dye laser is 6 to 10 or even larger. For example, for a typical system a equals 2 mm,  $l$  equals 0.5 to 0.5 meters and equals .5 micrometers. (2) The waveguide laser has resonator optics that match the free space  $TEM_{00}$  mode to some of the lower order waveguide modes such as the  $HE_{01}$  or  $HE_{11}$  mode. There is no such restriction in the present system. There is no unique curvature for the mirrors to go with the aperture of the waveguide as in the true waveguide laser. (3) Resonating modes are absent in the present system, and any ray that is reimaged on the exit/entrance aperture can have net gain. The beam divergence is large but still less than that emanating from a guide with a given numerical aperture, or from a tube whose optical beam divergence is defined by the aspect ratio of the tube. Because of the large beam divergence, tuning elements that depend on minimum beam divergence are not effective as line narrowing elements. However, etalons are effective and linewidths to .03 Angstroms have been obtained using the present system. Birefringent filters have also been used to tune the present system.

The present laser advantageously satisfies the criteria for selective photothermolysis. A dye laser emitting at 575 nm with pulse durations up to

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400 microseconds has been developed for the treatment of cutaneous vascular lesions such as birthmarks. Such birthmarks are caused by a high density of blood vessels close to the surface of the skin. These blood vessels can be eliminated by selective photothermolysis. The selective photothermolysis laser should emit at 575 nm where blood has secondary absorption maxima at least an order of magnitude larger than that of pigmented tissue of fair skin. The laser should emit pulses about one millisecond long to couple energy into the blood vessels which are several hundred microns in diameter. The vessel will then be heated to denaturation temperature without vaporizing the blood cells. The laser should then be turned off before tissue surrounding the blood vessels is damaged.

A laser with variable pulse duration can be used in selective photothermolysis for a number of medical treatments other than the treatment of cutaneous vascular lesions. These include hemostasis of bleeding ulcers, suppression of choroidal neovascularization that leads to blindness, and hemostasis after the removal of eschar in burn therapy. If exogenous chromophores can be selectively injected into target tissue, the principle of selective photothermolysis treatment with tunable, variable pulse duration lasers can be extended to cover many medical applications too numerous to mention.

Fig. 5 illustrates a modification of the system of Fig. 1 which is possible with the present system.

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Because the primary parameter of importance is the relation between the focal length of the optical system and the distance to the dye cell aperture and not the length of the dye cell itself, a bend as shown in the dye cell 36 of Fig. 5 is possible. With a conventional laser, that bend would provide different path lengths through the medium which would destroy the resonating modes of the system.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.



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CLAIMS

1. A multiple pass light amplifier comprising:

a cell having a medium excitable to an energy level with net optical gain and apertures at opposite ends thereof, the Fresnel number of the cell and optics being greater than one;

means for raising the energy level of the medium to have net optical gain; and

an optical system at each end of the cell for imaging each aperture near to itself .

2. A multiple pass light amplifier as claimed in Claim 1 wherein each optical system comprises a spherical mirror positioned at a distance from the aperture about equal to its radius of curvature.

3. A multiple pass light amplifier as claimed in Claim 1 wherein at least one of the optical systems comprises a flat mirror and a lens positioned between the mirror and the aperture at about the focal length of the lens from the aperture.

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4. A method of amplifying light to develop a pulsed beam of light at least 100 microseconds in duration and at least one tenth joule comprising:

05

for at least 100 microseconds,  
energizing a medium in a cell to an  
energy level in which the medium  
has net optical gain; and

15

from each end of the cell  
collecting substantially all light  
within a wavelength band emanating  
from the cell and returning the  
light into the cell such that the  
cell amplifies the light to form a  
spatially noncoherent beam of light  
of directional concentration to a  
solid angle substantially less than  
one steradian.

20

5. A method as claimed in Claim 4 wherein the  
spatially noncoherent beam of light has a  
directional concentration to a solid angle of  
about  $10^{-4}$  steradian or less.

25

6. A method as claimed in Claim 4 wherein the  
bandwidth of the amplified beam is reduced by  
means of a tuning element.

30

7. A system for generating a beam of light for  
selective photothermolysis comprising:

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a pulsed tunable dye laser for  
amplifying light to generate a  
spatially noncoherent beam of light  
with an energy level of at least  
about one joule and a pulse dura-  
tion greater than 10 microseconds;  
and

a pulse forming circuit for  
generating variable electric pulses  
for energizing the tunable dye  
laser, the pulse forming circuit  
providing variable length pulses  
through the range of at least about  
10 microseconds to 500 micro-  
seconds.

8. The system of Claim 7 wherein the pulse forming  
circuit generates pulses of about one milli-  
second duration.

9. The system of Claim 7 wherein the pulsed  
tunable dye laser comprises:

a cell having a dye solution  
excitable to an energy level with  
net optical gain and apertures at  
opposite ends thereof, the Fresnel  
number of the cell being greater  
than one;

means for raising the medium  
to the excited energy level; and

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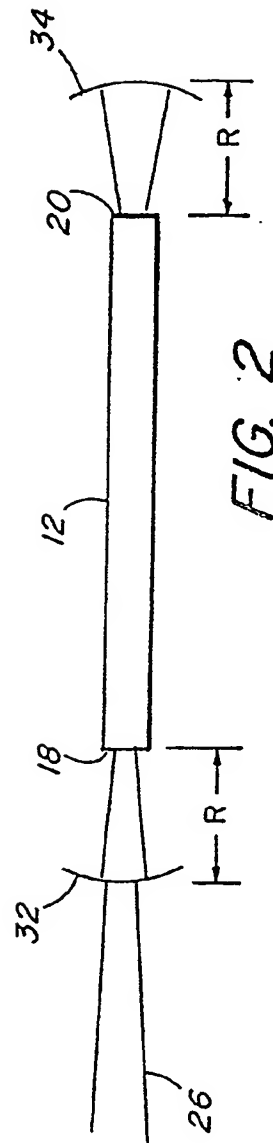
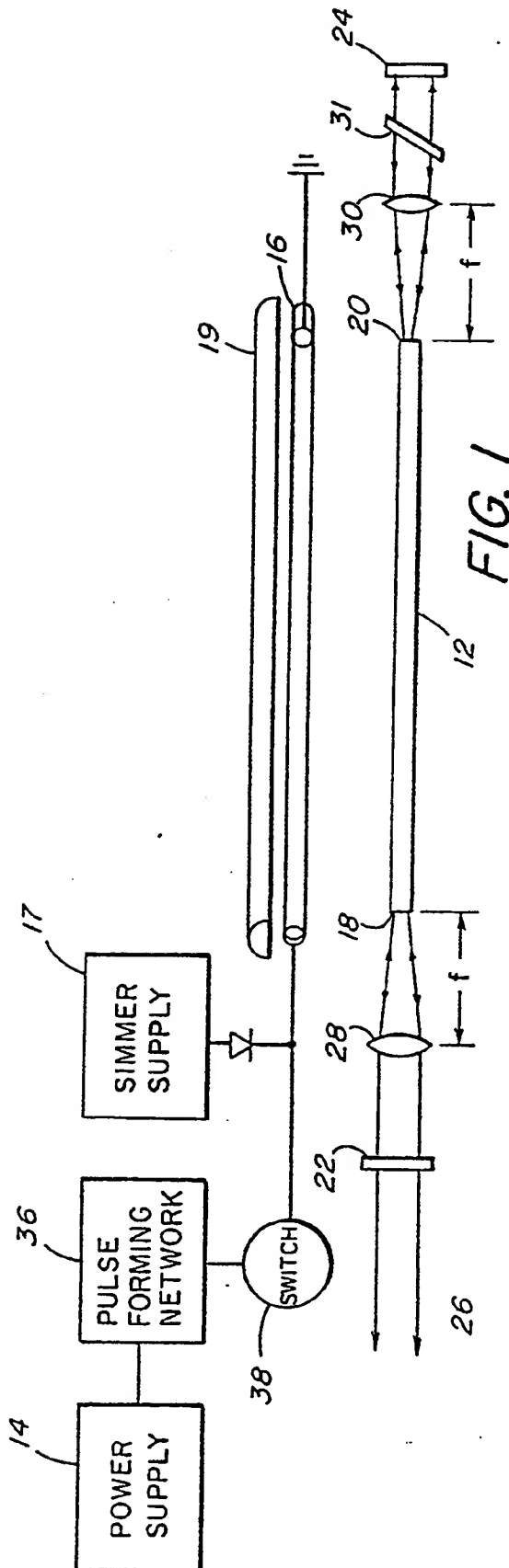
an optical system at each end  
of the cell for imaging each  
aperture near to itself such that  
substantially all light within a  
wavelength band emanating from the  
aperture is returned to the cell  
through the aperture until the  
light passes through one of the  
optical systems as a beam.

05

10

10. The system of Claim 9 further comprising a tuning element to tune the laser across the gain curve of the dye solution.

1/2



2/2

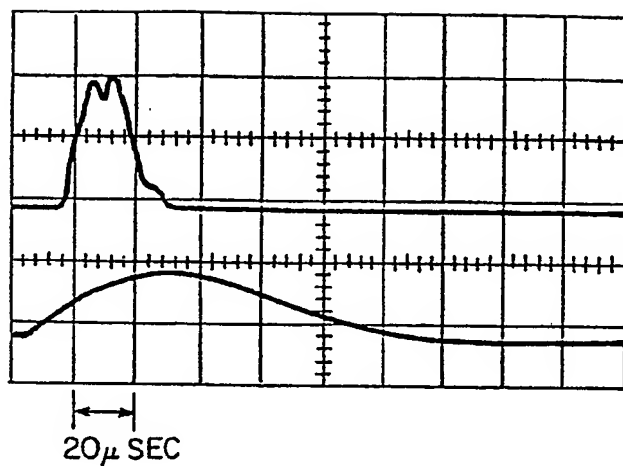


FIG. 3

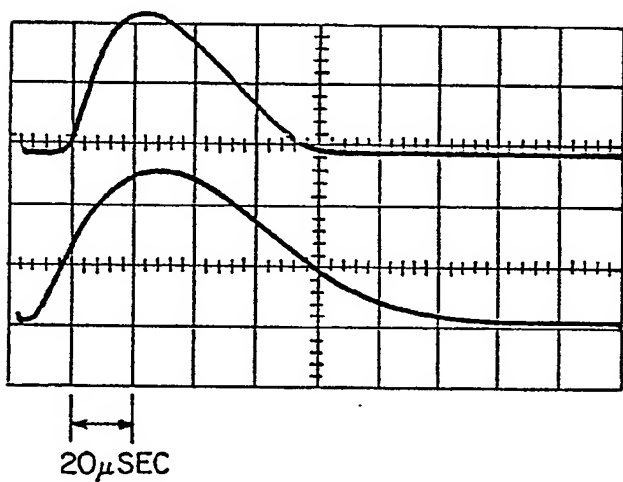


FIG. 4

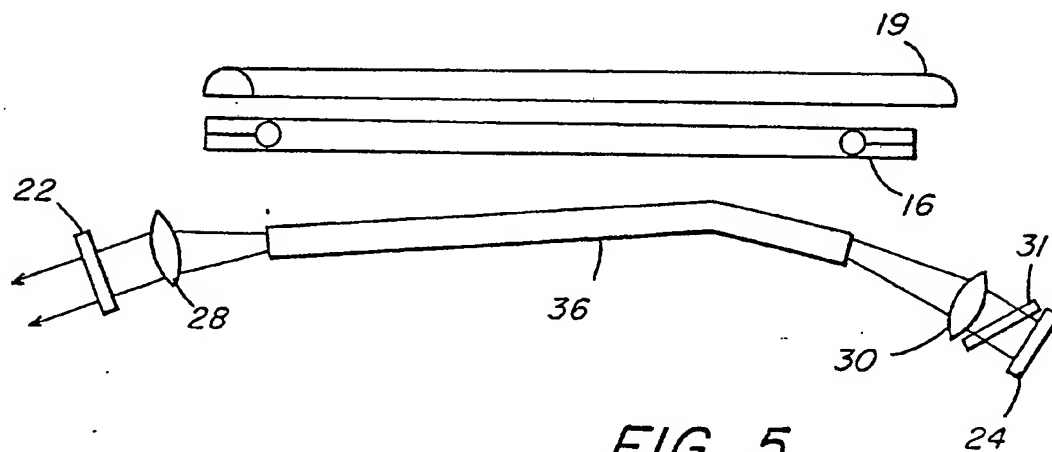


FIG. 5

# INTERNATIONAL SEARCH REPORT

International Application No PCT/US 85/02084

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (In several classification symbols shall indicate all) <sup>*</sup> According to International Patent Classification (IPC) or to both National Classification and IPC: IPC <sup>4</sup> : H 01 S 3/08; 3/106; 3/692; A 61 B 17/36		
<b>II. FIELDS SEARCHED</b> <div style="text-align: center; border-top: 1px solid black; border-bottom: 1px solid black; margin: 5px 0;">Minimum Documentation Searched<sup>7</sup></div> Classification System: IPC <sup>4</sup> Classification Symbols: H 01 S 3/08; 3/106; 3/092; 3/20		
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b>		
Category <sup>10</sup>	Citation of Document <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
A	IEEE Journal of Quantum Electronics, vol. QE-10, no. 10, October 1974 (New York, US) E.A. Maunders et al.: "Experiments on improved unstable mode profiles by aperture shaping", pages 821-822, see particularly figure 1 and page 821, right-hand column, paragraph 2	1
A	Optics and Spectroscopy, vol. 49, no. 5, November 1980 (New York, US) V.S. Smirnov: "Methods for reducing the divergence of lamp-excited rhodamine 6G solution lasers", pages 526-529, see particularly page 526, right-hand column - page 527, end of left-hand column	1-3,5
A	Applied Optics, vol. 21, no. 15, August 1982 (New York, US) J. Jethwa et al.: "High-efficiency high-energy flashlamp-pumped dye laser", pages 2778-2779, see figures 2,5-6	4,7 ./.
<div style="display: flex; justify-content: space-between;"> <div style="width: 48%;"> <p><sup>*</sup> Special categories of cited documents: (1)</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document relating to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 48%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"Z" document member of the same patent family</p> </div> </div>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search		Date of Mailing of this International Search Report
5th February 1986		28 FEB. 1986
International Searching Authority  EUROPEAN PATENT OFFICE		Signature of Authorized Officer  M. VAN MOL

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	Applied Optics, volume 18, no. 8, April 1979, New York, (US) T.K. Yee et al.: "Simmer-enhanced flashlamp-pumped dye laser", pages 1131-1132, see figure 1; page 1131, right-hand column, last two lines --	4,7
A	IEEE Journal of Quantum Electronics, volume QE-10, no. 8, August 1974, New York, (US) G. Holtom et al.: "Design of a Birefringent filter for high-power dye lasers", pages 577-579, see page 578, right-hand column, lines 7-8 --	6,10
A	US, A, 3426293 (ELIAS SNITZER) 4 February 1969, see claim 1 -----	1,6,10



**FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET**

**V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE**

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers ..... because they relate to subject matter not required to be searched by this Authority, namely:
  
2. ☐ Claim numbers ..... because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3. ☐ Claim numbers ..... because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

**VI. ☒ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING**

This International Searching Authority found multiple inventions in this international application as follows:

- see Annexe

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:
  
3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:
  
4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

**Remark on Protest**

- ☐ The additional search fees were accompanied by applicant's protest.
- ☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/210 (supplemental sheet (2))

Multiple inventions as follows:

- claims 1-3 : A multiple pass light amplifier comprising a cell with apertures and an optical system for imaging each aperture near to itself
- claims 4-6 : A method of amplifying light to develop a pulsed beam with a particular duration, energy and directional concentration
- claims 7-10 : A system for generating a beam of light for selective photothermolysis comprising a tunable dye laser with a particular excitation arrangement

- - -

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON  
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INTERNATIONAL APPLICATION NO.  
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PCT/US 85/02084 (SA 11203)  
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This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 21/02/86

The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 3426293	04/02/69	None	

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For more details about this annex :  
see Official Journal of the European Patent Office, No. 12/82